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The Suitability of Rapakivi Granite Varieties of the Wiborg Batholith for the Production of Asphalt Pavements

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Division of Geology and Mineralogy
Department of Geology
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ACADEMIC DISSERTATION

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Key words Wiborg batholith, rapakivi granite varieties, petrographic studies, laboratory tests, asphalt pavements, correlations, rock aggregate test roads, Finland.

ABSTRACT

The present study aims to determine, by means of the Swedish impact, abrasion, Nordic ball-mill, point-load and Los Angeles tests, the strength classes of the different rapakivi granite varieties occurring in the Wiborg batholith area of southeastern Finland and their suitability as road asphalt paving material. The quality classes are determined after the FinnRA work instructions. Certain petrographical factors affecting the strength and wearing resistance of rocks have also been examined. About 600 rock localities were mapped, from which 77 samples were taken for laboratory tests.

Features common to all the samples studied that do not fall below the II quality class (medium strength) are the fine- to medium-grained groundmass, the abundant occurrence of fine-grained quartz and the lack of clear microjointing. Among the 25 even-grained rapakivi granites studied, ten samples were identified as of II quality; among the 12 hornblende rapakivi granites, four; among the eight dark-coloured, even-grained rapakivi granites, one; and among the 32 porphyritic rapakivi varieties, one. The exploitation of most of the high-quality rock material localities is often limited by the small size of the occurrence (less than 50 000 tons) or by environmental factors.

The total length of the very busy roads (over 5 000 vehicles a day) in the Wiborg batholith area is 276 km. Roads having such a daily traffic volume require as asphalt paving material a rock of I quality (FinnRA's 1994 paving works instructions), and in the Wiborg batholith area it occurs only in connection with the Jaala-Iitti hornblende rapakivi granite complex. Less than 10 % of the Wiborg batholith bedrock material belongs to the III-quality class or better.

The average daily traffic volume on the Kouvola rock aggregate test road (built in September 1990) is 4900 vehicles (ADT 1990), and accordingly the requirement for the asphalt pavement rock material is at least II (FinnRA's 1994 paving works instructions). The average rut depth of the rock material of II quality (2 test road parts) is 1.9-2.7 mm and of III quality (6 test road parts) 4.3-5.2 mm (measured in May 1994).

In the light of the results obtained, it can be considered probable that the durability of the III-class rock material is not less than 10 years. Thus, weighing all the costs, it is probable that III-class rock material can be used on roads with the said traffic volume. Accordingly, the minimum quality requirements of crushed rock given by the 1992 FinnRA paving works instructions would come closer to real conditions than the requirements in the instructions of 1994.

The correlations between the Nordic ball-mill and point-load tests as well as between these tests and the wear of the surface on the Kouvola and Kerava test roads were highly significant. Also the correlation of the parallel Nordic ball-mill tests done on the rock aggregates and crushed Ø 32-mm core samples is highly significant (10 rock samples). The point-load test can therefore be omitted because the Nordic ball-mill test is technically easier to do and suits different rocks, besides being suitable also for quality guidance and control during crushing work, and pre-sampling when using core samples of rock aggregate.

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PREFACE

The use of crushed rock as road construction material has increased considerably in recent years. Of the crushed aggregate used in the Kymi Region in the year 1985, crushed rock accounted for only about 20 % of the total, but by 1990 no less than 65 %.

In 1986, the then Kymi Road and Waterway District decided to hire a geology student at the final stage of his studies to chart the rock resources of the region and to estimate their suitability as road construction material - particularly in the form of rock material to be used in road pavements. The undersigned carried out the charting of the rock occurrences and the study of the rock samples for the most part in the years 1986-89, resulting in the charting of some 650 bedrock areas. The main areas involved in the present study are located in the central and western parts of the region; thus nearly all the bedrock areas charted (approximately 600) are located in the area of the Wiborg rapakivi batholith.

Before the present study was made, the following reports had been written:

Vallius, P., 1989. Tien päällystekiviaineeksi soveltuvien kallioalueiden etsintä ja näytteenotto sekä kiviaineksen kulutuskestävyys. (= The search for and sampling of bedrock areas likely to provide rock material for road pavements, and the resistance of the rock to wear). Unpublished academic thesis. Department of Geology, University of Helsinki, 31 p.

Vallius, P., 1991. The suitability of the different rapakivi types from the Wiborg rapakivi batholith to asphalt concrete pavements. In I. Haapala & O. T. Rämö (editors), Symposium on Rapakivi granites and related rocks, abstract volume. Geological Survey of Finland, Guide 34, 55.

Vallius, P., 1992a. Viipurin batoliitin eri rapakivityyppien soveltuvuus tienpäällystekiviaineeksi. Unpublished academic thesis of Licentiate in Philosophy. Department of Geology, University of Helsinki, 102 p.

Vallius, P., 1992b. Viipurin batoliitin eri rapakivityyppien soveltuvuus tienpäällystekiviaineeksi. Tielaitoksen tutkimuksia 3 (TIEL 310 0004). Suitability of the different Wiborg batholith rapakivi types to asphalt concrete pavements. Finnish National Road Administration (FinnRA). Research Report 3, 89 p.

Regional Director Ville Mäkelä and Juha Kosonen, M.Sc.Eng., made possible the execution of this study by arranging the necessary financial support. Vice Director General Jarkko Saisto of the Finnish National Road Administration arranged for its publication in the administration's series of reports. Professor Ilmari Haapala of the Department of Geology, University of Helsinki, actively guided the execution of the research project. Professor Kalevi Kauranne and Assistant Professor Raimo Uusinoka gave valuable counsel and suggestions for the improvement of the manuscript. Paul Sjöblom checked and corrected the English translation.

In collecting the rock samples, I was assisted by Hannu Valtonen and Risto Vallius. Esa Pajunen and Matti Leppänen did most of the laboratory work involved in the research project at the Kouvola Laboratory of the Southeast Region of the FinnRA. In handling the statistical material, I have benefited from the assistance given me by Messrs. Ari Jokela, Arto Hovi and Matti Varjus. The map of the research area was copied for reproduction by Ms. Sinikka Korhonen and Ms. Eila Katajala. The layout was done by Mmes. Marjatta Kossila and Anna-Maija Pomell-Kuusela.

Senior Inspector Martti Eerola, geologist, arranged me possibilities to perform part of the laboratory work involved in the Geotechnics Laboratory of FinnRA. In the course of my research, I also received good advice from Senior Inspector Kari Lappalainen, a geologist of the Geotechnics Laboratory of FinnRA.

It pleases me to express my appreciation to all the persons mentioned in the foregoing as well as to everybody else who helped me carry out this research project.

Kouvola 10 VIII 1994 Pekka Vallius

To Suvi-Tuulia and Pauli

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1 INTRODUCTION

In addition to *sauna*, there is another Finnish word known in all the civilized languages in its original form: *rapakivi.* In spite of its name (meaning "crumbly rock" or "rotten stone"), rapakivi is generally a solid, durable variety of granite, which is frequently used in the building trade and which is also associated with occurrences of high-grade semiprecious stone.

The history of the term rapakivi dates back as far as at least the 1600s. The word rapakivi became known from Finnish-speaking peasants, who used it to refer to the tendency of certain outcrops and boulders to weather into crumbly rock or gravel (= "moro"). Rapakivi granite was introduced to the international geological literature by the renowned Finnish geologist J. J. Sederholm in 1891 through his study *"Ueber die finnländischen Rapakiwigesteine".* Since then, southern Finland has been regarded as the world's typical rapakivi granite region, notwithstanding the fact that rapakivi granites occur in all the continents (Haapala 1988).

Since the appearance of Sederholm's work (1891), the studies made of the rapakivi granites in Finland have traditionally concentrated on petrological, mineralogical, geochemical and metallogenetic questions (e.g., Wahl 1925; Eskola 1930; Sahama 1945; Savolahti 1962; Simonen & Vorma 1969; Vorma 1971, 1972, 1975; Haapala 1977a, 1977b; Vaasjoki 1977; Rämö 1991).

Since the 1800s, rapakivi granites have been favored as construction material, and in recent years relatively extensive studies have been done on rapakivi granites as commercial stones (Kymenlaakson seutukaavaliitto & Etelä-Karjalan seutukaavaliitto 1989; Etelä-Karjalan seutukaavaliitto & Kymenlaakson seutukaavaliitto 1990). In these research works, attention has been focused not only on the suitability of rapakivi granites as construction material (dimension stone) but also on their suitability for use as crushed rock.

The features and practical value of rock materials from Finland's bedrock were studied on a large scale by Kauranne (1970a, 1970b). His research was based on analyses of over 5000 samples of gravel and rock sent in 1961-68 to the laboratory of the National Board of Public Roads and Waterways (=FinnRA).

A major research program, known as the ASTO project, dealing with asphalt pavements was carried out in Finland during the years 1987-92. The ASTO project focused primarily on the features of rock materials and binders and different additives of bitumen, as well as on the mixing, laying and compaction of the mass. The research was aimed primarily at increasing the wearing resistance of asphalt pavements. The Technical Research Center of Finland (VTT) and the Finnish National Road Administration (FinnRA) participated in the field in this research, together with the institutions of higher education.

The ASTO project involved ten working groups, of which the Rock Material Group was one (TR 2). The Rock Material Group has published new information about the features of rock materials used to make asphalt pavements and of binders, about the methods of testing rocks, as well as about excavating and crushing methods (Lappalainen 1988; Nieminen 1988; Uusinoka 1988; Heikkilä et al. 1990; Nieminen & Jäniskangas 1990; Pylkkänen & Kuula-Väisänen 1990a, 1990b; Alkio & Vuorinen 1990, 1992a, 1992b, 1993).

Table 1. Length of public roads (km) and average daily traffic volume (ADT automobiles) in the Wiborg rapakivi batholith area, and their percentage of the total public road length in the Kymi and Uusimaa Regions of FinnRA. See Fig. 1.

Kymi Region

ADT automobiles	Main highways (I class)		Main highways (II class)		Other highways		Local roads	
	km	%	km	%	km	%	km	%
>10 000	32	(82)	1	(100)	1	(100)	-	
5 000-10 000	165	(88)	-		16	(70)	-	
1 000- 5 000	133	(45)	51	(51)	253	(87)	44	(60)
< 1 000	12	(80)	7	(33)	560	(49)	1216	(63)
Total	342	(64)	59	(48)	830	(57)	1260	(63)

Uusimaa Region

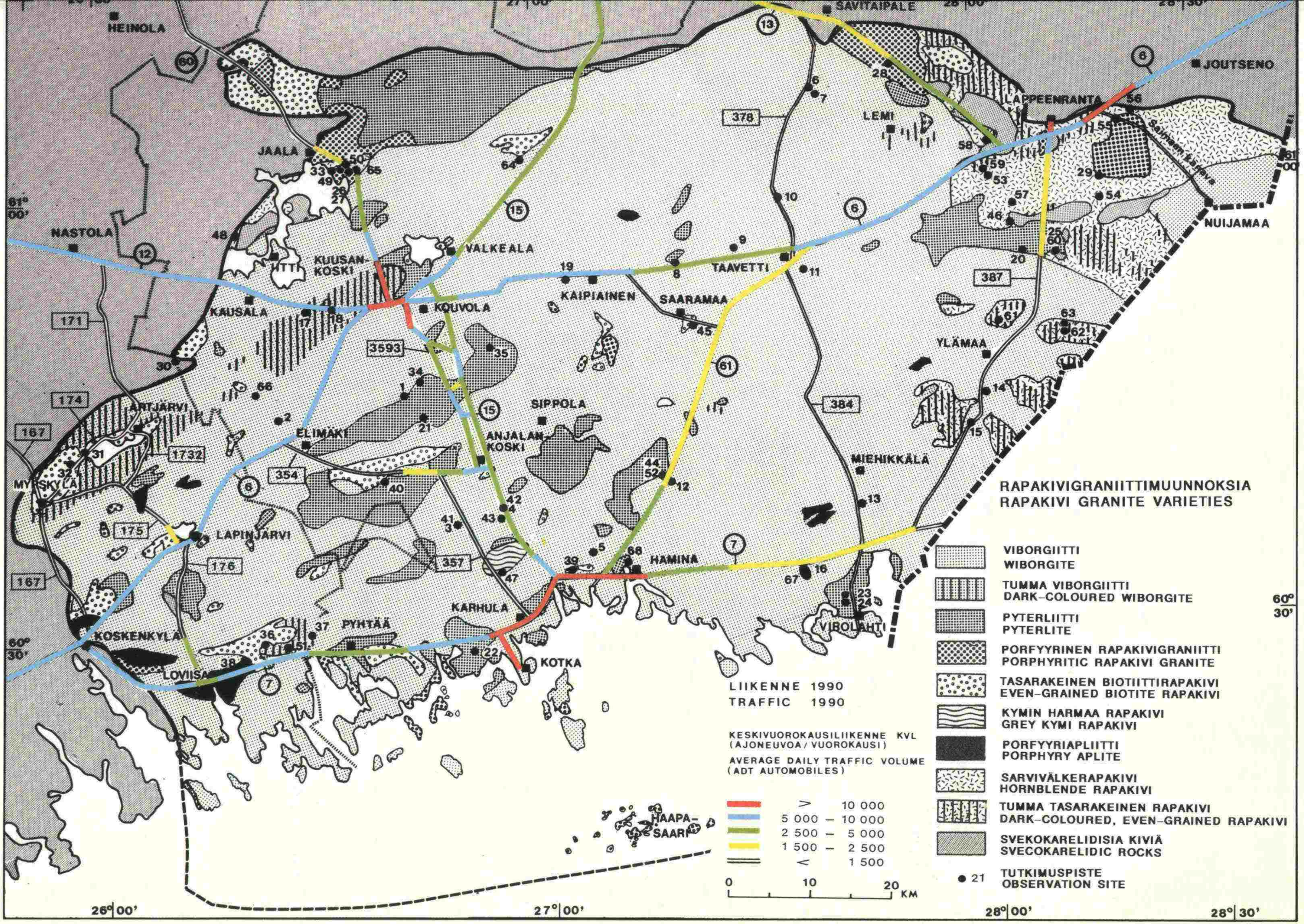
ADT-automobiles	Main highways (I class)		Main highways (II class)		Other highways		Local roads	
	km	%	km	%	km	%	km	%
>10 000	-		-		-		-	
5 001-10 000	57	(41)	-		4	(3)	-	
1 000- 5 000	5	(42)	-		30	(4)	4	(1)
< 1 000	-		-		163	(18)	186	(10)
Total	62	(16)	-		197	(10)	190	(8)

The area covered by the present research includes the Finnish side of the Wiborg rapakivi batholith, the superficial inland part of which is about 8500 sq. km. Most of this area (about 7400 sq. km) is situated in the Kymi Region of FinnRA (= Kymen tiepiiri)[1)] and the western part (about 1100 sq. km) in the Uusimaa Region of FinnRA (= Uudenmaan tiepiiri). Figure 1 shows the geographical location of the research area.

The total length of the road network in the Uusimaa Region is 4921 km, and 449 km of this is to be found in the Wiborg batholith area. The total length of the road network in the Kymi Region is 4112 km, most of which, 2491 km, is in the Wiborg batholith area. Over 80 % of the heavily trafficked main highways of the Kymi Region, where the average daily traffic volume (ADT) is over 5000 vehicles a day, are in the Wiborg batholith area (Table 1).

Fig. 1. Map showing different rapakivi varieties, observation sites, main highways and average daily traffic volume in the Wiborg batholith area. The bedrock map is based on the bedrock maps of Frosterus (1900), Hackman & Berghell (1931) and Härme (1980) as well as on field observations reported by Vallius (1992a, 1992b). The traffic volume is calculated for the Kymi and Uusimaa Regions on the basis of FinnRA (Tielaitos, Kymen tiepiiri, 1990; Tielaitos, Uudenmaan tiepiiri 1990).

1) On January, 1994, the Kymi and Mikkeli Regions of FinnRA (= Kymen tiepiiri and Mikkelin tiepiiri) were merged to form the Southeastern Region of FinnRA (= Kaakkois-Suomen tiepiiri).



RAPAKIVIGRANIITTIMUUNNOKSIA
RAPAKIVI GRANITE VARIETIES
VIBORGIITTI
WIBORGITE
TUMMA VIBORGIITTI
DARK-COLOURED WIBORGITE
PYTERLIITTI
PYTERLITE
PORFYYRINEN RAPAKIVIGRANIITTI
PORPHYRITIC RAPAKIVI GRANITE
TASARAKEINEN BIOTIITTIRAPAKIVI
EVEN-GRAINED BIOTITE RAPAKIVI
KYMIN HARMAA RAPAKIVI
GREY KYMI RAPAKIVI
PORFYYRIAPLIITTI
PORPHYRY APLITE
SARVIVÄLKERAPAKIVI
HORNBLENDE RAPAKIVI
TUMMA TASARAKEINEN RAPAKIVI
DARK-COLOURED, EVEN-GRAINED RAPAKIVI
SVEKOKARELIDISIA KIVIÄ
SVECOKARELIDIC ROCKS
• 21 TUTKIMUSPISTE
OBSERVATION SITE
LIIKENNE 1990
TRAFFIC 1990
KESKIVUOROKAUSILIIKENNE KVL
(AJONEUVOA / VUOROKAUSI)
AVERAGE DAILY TRAFFIC VOLUME
(ADT AUTOMOBILES)
> 10 000
5 000 – 10 000
2 500 – 5 000
1 500 – 2 500
< 1 500
0 10 20 KM
HEINOLA
NASTOLA
JAALA
KUUSANKOSKI
KAUSALA
VALKEALA
KOUVOLA
ELIMÄKI
ARTJÄRVI
MYRSKYLÄ
LAPINJÄRVI
KOSKENKYLÄ
LOVIISA
PYHTÄÄ
KARHULA
KOTKA
ANJALANKOSKI
SIPPOLA
KAIPIAINEN
SAARAMAA
TAAVETTI
HAMINA
HAAPASAARI
VIROLAHTI
MIEHIKKÄLÄ
YLÄMAA
LEMI
SAVITAIPALE
LAPPEENRANTA
JOUTSENO
NUIJAMAA
Saimaan kanava
26°00'
27°00'
28°00'
28°30'
60° 30'
61° 00'

The length of the most heavily trafficked roads (ADT over 10 000) in the Wiborg batholith area of the Kymi Region is about 34 km. Figure 1 shows that they, mostly highways, are situated in the Kotka - Karhula - Hamina and the Kouvola and Lappeenranta areas.

The main purpose of the present study is to determine the suitability of the rapakivi granite varieties of the Wiborg batholith for the production of asphalt pavements and to investigate the accessibility of rock materials. In addition, it is aimed to determine the correlations between various laboratory strength tests done on different rapakivi samples and to compare the findings made on the rock materials used on the Kerava and Kouvola rock aggregate test roads.

The factors affecting the strength and wearing resistance of the rock as well as the specification methods applied in the case of the features investigated are reported at the beginning of the present study. In the primary research, the petrographic features of the different rapakivi granite varieties and the specific features of each observation site are described on the basis of the material studied. After the petrographic description, attention is focused on the technical features of the rapakivi varieties.

The study is based on the mapping work done on the Wiborg batholith bedrock in 1986-1989 (Vallius 1992a, 1992b). The bedrock maps drawn on the scale of 1:100 000 (Laitakari & Simonen 1962; Simonen & Lehijärvi 1963; Laitala 1964; Lehijärvi 1964; Vorma 1964; Simonen 1965, 1973, 1975, 1979a, 1979b; Simonen & Tyrväinen 1965; Meriläinen 1966; Lehijärvi & Tyrväinen 1969; Simonen & Laitala 1970, 1972) have been used to facilitate the mapping work.

About 600 possible rock quarry localities were mapped, from which 77 samples were taken for laboratory tests. Thin sections have been made of all the samples for microscopical study. In addition, the following examinations and determinations have been made in the Kymi Region Laboratory: specific gravity, shape index, Los Angeles test, point-load test, Nordic ball-mill test; and the following ones in the Geotechnics Laboratory of FinnRA: Swedish impact test, abrasion test.

2 FACTORS AFFECTING THE STRENGTH AND WEARING RESISTANCE OF ROCK ACCORDING TO PREVIOUS STUDIES

The most important factors affecting the strength and wearing resistance of rock are the mineral composition and textural features of the rock (grain size of minerals, grain shape of minerals and arrangement of mineral grains) as well as the rate of decay and breakability of the rock (Kauranne 1970b; Jumikis 1983). Several igneous and metamorphic rocks may contain rock types suited to asphalt pavements. Examples that can be mentioned are gabbro, diorite, granite, rapakivi granite, gneiss, volcanite, diabase and quartzite.

2.1 Mineral composition

The mineral composition of the rock affects essentially the mechanical strength of the rock, because different minerals have physical and chemical properties deviating remarkably from each other. Rocks best suited as asphalt paving materials consist of hard minerals resistant to scratching, such as quartz and feldspars. As to impact resistance, the hard minerals contained in the rock should have small amounts of evenly spread smoother and tenacious minerals, such as amphiboles, pyroxenes and biotites (Kauranne 1970b; Lappalainen 1987).

2.2 Grain size of minerals

As for textural features, the grain size of minerals clearly affects the strength and wearing resistance of rocks. In coarse-grained rocks, the friction and cohesion surfaces between individual mineral grains as well as the friction and cohesion forces per volume unit are smaller than in fine-grained rocks. The coarse-grained rocks are thereby weaker than the fine-grained rocks (Carroll 1970; Kauranne 1970b).

The grain size of minerals has an effect on not only the strength but also the fragment size distribution when the rocks undergo crushing. During crushing, fine-grained rocks form fine-grained mineral fractions in abundance, because the rock breaks easily into a monomineral and further even finer, but considerably harder, grade. Besides the grain size of minerals, the structure of the rock, the type of the crusher and its adjustment affect the fragment size distribution of the crushed material (Kauranne et al. 1972; Lappalainen 1987).

2.3 Grain shape of minerals

The shape (crystal form) of the grain of rock-forming minerals affects the strength of solid rock. Rocks that have an abundance of minerals with smooth grain boundaries are weaker than rocks with surfaces composed of irregular formed or serrated grains (Kauranne 1970b).

2.4 Arrangement of mineral grains

The arrangement of the mineral grains also affects the strength and wearing resistance of rock because minerals differing from each other in their physical properties can, when occurring as groups and zones, form weak planes where the rock most easily breaks down. When minerals differing from each other in their physical properties are evenly distributed all over the rock, no distinct weak points will appear in it (Korhonen et al. 1974).

The importance of the arrangement of the mineral grains is to be noted in, for instance, mica gneiss. In mica gneiss, the solid, often banded micaceous portions form breaking surfaces in the rock.

Taking into consideration the orientation of the minerals, the toughest rocks are non-orientated or only weakly orientated. The minerals that are non-orientated and differ from each other in grain form and size and are distributed evenly throughout the rock form an especially strong structure (Kauranne et al. 1972; Lappalainen 1987).

The orientation of the rock-forming minerals affects not only the strength (differing in different portions of the rock) but also the form of the rock fragments produced by rock crushing. When distinctly orientated rock undergoes crushing, particles with the shape of plates or sticks will be produced more easily than in the crushing of non-orientated rocks (Kauranne 1970b).

2.5 Physical weathering

The physical weathering of the rock appears as abundant jointing and microjointing. The rock breaks primarily as a result of differential movements of the bedrock. During such movements, the rock is broken, crushed and abraded, producing weak zones in the bedrock (Holmes 1965).

In the Precambrian area of Southern Finland the fracture zones on valley bottoms differ noticeably from the fractures sometimes seen in outcrops or in surficial sections of the bedrock. Compared with the latter, the fracture zones on the valley bottoms seem to be longer, less healed, and more fractured and chemically weathered (Niini 1968).

The physical weathering of the rock clearly affects its strength and wearing resistance, because under mechanical stress rock fragments having jointings and microjointings will break more easily than solid fragments. Also in asphalt pavements, broken rock grains emerge and wear out faster than fragments of solid rock.

2.6 Chemical weathering

The chemical weathering of rock causes loss of strength, because during the decomposition the minerals alter to other, often weaker minerals. Alteration occurs especially at the edges of the grains, and this tends to weaken the grain cohesion. Easily soluble minerals, e.g., calcite and sulphides, dissolve little by little weakening the rock (Holmes 1965; Uusinoka 1983).

The alteration of feldspars, biotites and amphiboles, in especial, has to be taken into consideration in microscopical studies of rock. If the rock seems clearly to be chemically weathered, it will not be suitable for the production of asphalt pavement (Uusinoka et al. 1990).

All sulphide ore minerals, e.g., pyrrhotite, chalcopyrite, pyrite, sphalerite and galena, are sensitive to chemical decomposition (Kauranne et al. 1972). If sulphide minerals appear in rocks as fine impregnation, such rocks decompose more easily than those in which sulphide minerals appear as rare, large grains (Korhonen et al. 1974). In Finland, the chemical weathering is so slow that its influence will not generally appear for 5-10 years (Uusinoka 1988).

3 METHODS OF DETERMINING THE STRENGTH AND WEARING RESISTANCE OF ROCK

The suitability of rock as road construction material is determined mostly on the basis of the results of laboratory tests done on crushed rock samples. In recent years, the following laboratory tests and determinations have been made with rocks: determination of the specific gravity, determination of the shape index, Swedish impact test, Los Angeles test, abrasion test, point-load test and Nordic ball-mill test. In special studies, e.g., the Tröger test and the SRK test have been made, in addition.

3.1 Specific gravity

Specific gravity determinations are generally made in the laboratory by weighing rock samples in the air and in water (Tielaitos 1991b). On the basis of air weighing (W1) and water weighing (W2), the specific gravity of a sample (g/cm^3) can be calculated using the formula:

$$\text{specific gravity} = W1 \; / \; W1 - W2.$$

3.2 Shape index

The shape index of a crushed rock sample (8-12 mm or 12-16 mm) is determined by the elongation and flakiness of the rock grains. The shape index is determined using the TIE 233 method (Tielaitos 1991b). The shape index is defined alternatively after the flakiness determined according to the eurostandard determination, prEN 933-6 (Tielaitos 1993b).

The shape of the rock grains affects the resistance to wear of asphalt pavement as a result of the fact that plate- or stick-shaped grains cause an increase in the amount of empty space in the pavement. The resistance of pavement containing abundantly such rock grains in the mass must obviously be weaker than in the case of "cubic" rock fragments (Eerola & Alkio 1984).

The characteristics of both the variety of rock and the crushing methods and equipment have their effect on the shape index. The determination of the shape index is no exact research method; the results obtained by different determinations done on the same rock samples may differ markedly from each other (Kauranne 1970b).

3.3 Los Angeles test

The Los Angeles test is made to investigate the wearing and impact resistance of rock. The test is done with a so-called Los Angeles mill, where 5.0 kg of crushed rock (diameter 9.5-19.0 mm) is milled in a steel cylinder together with 11 steel balls. The Los Angeles value is determined according to the TIE 231 method (Tielaitos 1991b). The Los Angeles test is found to be a relatively reliable laboratory test, thanks to its easy repetition and the small dispersion of the results.

3.4 Swedish impact test

The Swedish impact test determines the impact resistance of the rock. The test is done by crushing about 0.5 kg of crushed rock (diameter 8-12 mm) in a small steel cylinder with a stroke hammer. The Swedish impact value is determined according to the TIE 232 method (Tielaitos 1991b).

On the basis of the research done in the Geotechnics Laboratory of FinnRA, the precision of the Swedish impact test does not come up to that of the Los Angeles test. On the basis of the Swedish impact test, the results yielded by parallel samples may deviate as much as 10 % from the average (Lappalainen 1987).

3.5 Abrasion test

The abrasion test determines the resistance of the rock to scratching and wear from contant grinding. For the test, two sample plates of 85 mm x 85 mm are made from the crushed (8-12 mm fraction) and cemented rock grains. Both sample plates have 36 pcs of rock grains, which are placed slightly apart from each other. The sample plates are ground against the grinding surface made of cast iron with abrasive powder consisting of aluminum-titanium oxide for 500 rotations. The abrasion value is determined according to the TIE 237 method (Tielaitos 1991b).

3.6 Point-load test

The point-load strength index gives the biggest load-bearing capacity of the rock before it breaks down with the load concentrating almost on one point. The point-load test is performed with a point-load apparatus or with a press, using either a core sample or a rock fragment of indefinite shape (ISRM 1985).

According to the FinnRA's work instructions for 1994 (Tielaitos 1993b), the point-load test is performed using only a core sample 32-62 mm in diameter. The point-load strength index is determined by the TIE 241 method (Alkio & Vuorinen 1993).

3.7 Nordic ball-mill test

The Nordic ball-mill test determines the wearing resistance of the rock. The test is performed with a mill apparatus, about 1 kg of crushed rock (fraction 11.2-16.0 mm) being rolled in a steel cylinder with steel balls and water. The Nordic ball-mill value is determined by the TIE 242 method (Alkio & Vuorinen 1993).

3.8 Tröger test

The Tröger apparatus, which was developed in Germany, is generally used to test the resistance to wear of experimental asphalt samples. The apparatus may, however, also be used to study rock samples. The wear caused by studded tires is simulated with it by pin pricks and scratches on such samples. The Tröger value is determined by the TIE 438 method. The Tröger test has been observed to be poorly suited to rock studies, its chief drawback being the varying results obtained with different apparatus (Alkio & Vuorinen 1992a, 1993).

3.9 SRK test

The so-called SRK apparatus developed at the Technical Research Center of Finland (VTT) has been designed mainly for the purpose of studying the resistance to wear of pavement samples prepared from asphalt mixtures. The apparatus may also be used to study samples drilled from solid rock. The wear caused by studded tires in traffic is simulated by the apparatus with blows and scratching made with studs normally used on the tires of automobiles. The SRK value is determined by the TIE 406 method. The SRK test is poorly suited to the study of rock samples, the biggest drawback being the difficulty of preparing the experimental pieces (Alkio & Vuorinen 1992a, 1993).

3.10 Microscopical studies

Rock samples are examined under a binocular stereomicroscope using 1-10 x magnifying objectives. Thereby, the main minerals and textural features of the rock can be determined relatively well. For more exact studies, thin sections are made from the rock samples to be examined with a polarizing microscope using 1-40 x objective magnification and 10 x ocular magnification.

The minerals occurring in the rock and their percentual amounts (modes) are determined from the thin sections. The percentages are determined by the point-counting method. In addition, the grain size of the main minerals and the average grain size of the samples can be estimated. If the rock sample is coarse-grained, the percentual content and grain size of the minerals have to be determined using a binocular stereomicroscope.

When the rock texture is studied, attention has to be paid especially to the alteration, grain boundaries and grain shape of the minerals and to possible microjointings. The Vicker's hardness can also be determined from the rocks, by calculating the average value of the main minerals weighted by the percentual amount of the minerals.

3.11 Other methods

In the following, certain testing methods will be discussed that are not normally used in testing rocks for asphalt pavements. Besides the wear test of bore samples, these methods involve so-called rock-mechanical strength and boring tests, such as: modulus of elasticity, Poisson's ratio, compression strength, tensile strength, Siever's J' value, Proto 20'-value, Swedish impact S20' value and bore penetration index. Further information about these testing methods is given by, e.g., Lappalainen (1987).

In addition to polarizing microscopic study, the texture of rock can be examined by X-ray diffraction analysis. Besides the results of X-ray analysis, also the specific surface area, pore distribution and water adsorption characteristics can be measured from the fine material of crushed rock to get an idea of the weathering resistance and the adhesive properties (Nieminen & Uusinoka 1986; Uusinoka & Peltonen 1988; Nieminen & Jäniskangas 1990; Alkio & Vuorinen 1993).

4 PETROGRAPHIC DESCRIPTION

4.1 General

All the rapakivi varieties are anorogenic non-metamorphosed, non-orientated mostly coarse-grained porphyritic granites. In chemical composition, the rapakivi granites are characterized by high potassium and low calcium and magnesium contents (Simonen 1987). In Table 2, it can be noticed that porphyritic rapakivi varieties are dominant (wiborgite - dark-coloured wiborgite - pyterlite - porphyritic rapakivi granite), accounting for nearly 90 % of the whole area.

The rapakivi granites of southern Finland form four large batholiths (Wiborg, Åland, Vehmaa, Laitila) and several small batholiths and stocks. The present erosion levels represent the upper part of the epizonal intrusive complexes. The Wiborg rapakivi batholith and associated mafic rocks were emplaced mainly between 1650 and 1625 Ma (Rämö et al. 1989; Vaasjoki et al. 1991).

The Wiborg batholith contains xenoliths of both svecokarelidic and subjotnian rocks, which are slightly older than the rapakivi granites (Fig. 2). The suitability of the xenoliths in the Lappeenranta and Ylämaa areas as asphalt paving material has been studied more closely. Targets for exploitation are found in the Taalikkala and Toivarila areas and also to the west of Lappeenranta in the Yllikkälä area (Ruoholammi area), where plagioclase porphyrite has been quarried for asphalt pavements.

Table 2. Distribution of the rapakivi granite varieties in the Finnish part of the Wiborg batholith. The proportions of the several varieties have been calculated from Fig. 1.

Wiborgite	74.4	%
Dark-coloured wiborgite	2.9	%
Pyterlite	9.7	%
Porphyritic rapakivi granite	2.3	%
Even-grained biotite rapakivi	3.1	%
Grey Kymi rapakivi	0.2	%
Porphyry aplite	0.7	%
Quartz porphyry	< 0.1	%
Hornblende rapakivi	4.3	%
Dark-coloured, even-grained rapakivi (tirilite)	2.4	%

Some rapakivi varieties disintegrate easily. The disintegration of rapakivi granites has been studied by, for instance, Eskola (1930), Savolahti (1962) and Vuorinen et al. (1981).

According to Eskola, the porphyritic rapakivi granites disintegrate more readily than other rapakivi varieties. The main reason for disintegration is the rapakivi texture: large-sized, euhedral mineral grains are joined together with smooth boundaries. Also the mineral composition contributes to the disintegration of the rock; rapakivi varieties containing mafic minerals, like biotite and hornblende, are more likely to disintegrate than corresponding aplitic varieties.

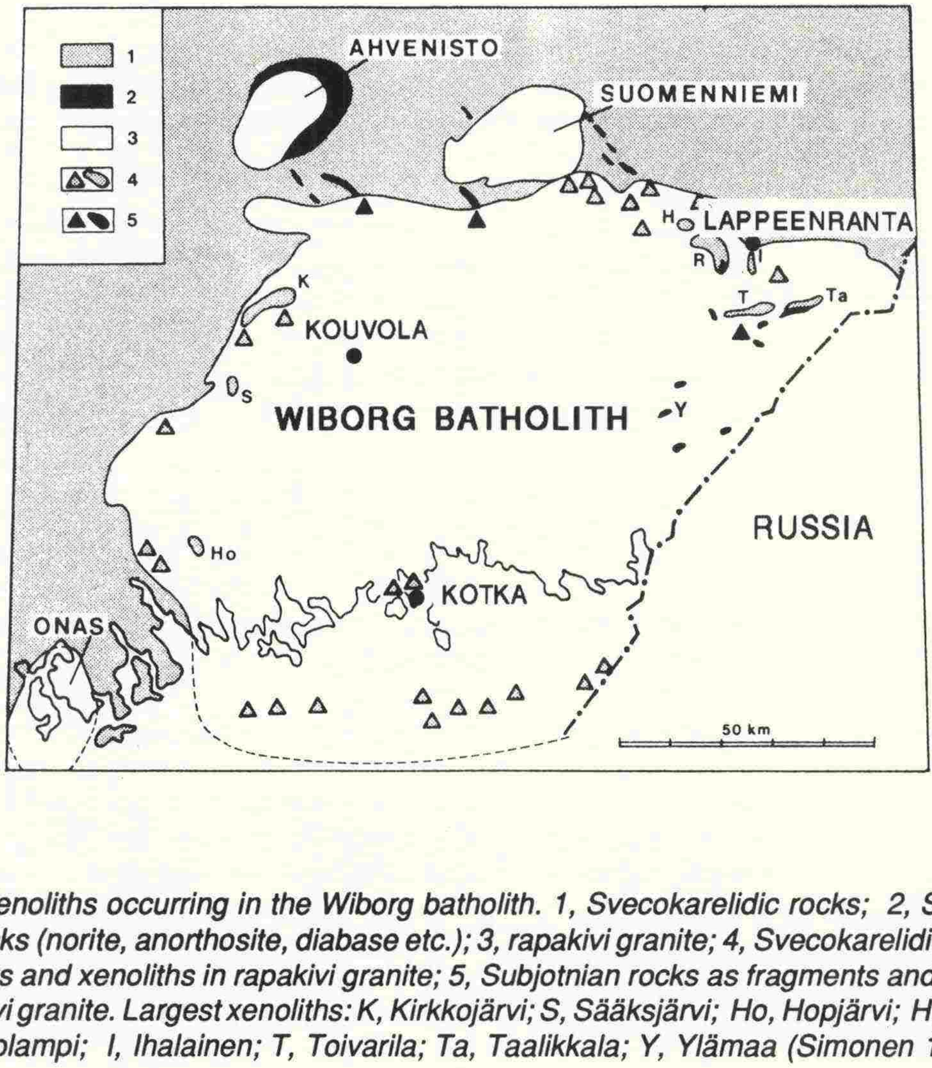


Fig. 2. Xenoliths occurring in the Wiborg batholith. 1, Svecokarelidic rocks; 2, Subjotnian mafic rocks (norite, anorthosite, diabase etc.); 3, rapakivi granite; 4, Svecokarelidic rocks as fragments and xenoliths in rapakivi granite; 5, Subjotnian rocks as fragments and xenoliths in rapakivi granite. Largest xenoliths: K, Kirkkojärvi; S, Sääksjärvi; Ho, Hopjärvi; H, Hyvärilä; R, Ruoholampi; I, Ihalainen; T, Toivarila; Ta, Taalikkala; Y, Ylämaa (Simonen 1987).

The consistency of bedrock might also have been weakened as a result of deformation of the earth crust. When rocks have fallen into the range of action of exogenetic processes (e.g., freezing and melting of water in the cracks of the bedrock), the result is disintegration of the rock, i.e., the moro.

According to Savolahti (1962), the main reason for a high tendency toward disintegration might be the high crystallization temperature of rapakivi and the violent contraction of minerals during the cooling of the rock, especially quartz (see Skinner 1966). Contraction causes cracking of the mineral grains, the minerals being separated from each other or at least the seams between the mineral grains being opened.

Vuorinen et al. (1981) have studied the effect of bacterial action on the disintegration of rapakivi. In their laboratory tests, they treated rapakivi granite samples with a bacteria culture solution. On the basis of the test results, they discovered that the bacteria caused a transformation of the surface structure of minerals, and increased the contents of Na, Ca, K, Fe and Mg in the culture solution. On the basis of this research, it is difficult to say to what extent the reactions caused by bacterial action occur in natural conditions.

4.2 Character of the different rapakivi varieties

4.2.1 Mineralogy, textural features and susceptibility for disintegration of different rapakivi varieties

The rapakivi varieties differ from each other mainly in mineral composition and textural features, and to some extent in regard to the abundance of microjointing and disintegration of the rock (Tables 3 and 4).

The commonest mineral of the rapakivi varieties is potassium feldspar, the content of which is generally 40-65 %. Pyterlites, most porphyritic rapakivi granites, even-grained biotite rapakivi granites, porphyry aplites and wiborgites have the highest content of potassium feldspar. The lowest content of potassium feldspar occurs in some hornblende rapakivi granites and dark-coloured, even-grained rapakivi granites (Table 3). The potassium feldspar occurs as euhedral phenocrysts and ovoids (gen. Ø 1-6 cm) and anhedral grains in the groundmass.

The highest quartz content (37-40 %) occurs in several even-grained biotite rapakivi granites. The quartz is usually dark in colour, is typically euhedral and has a grain size of 2 to 10 mm. Also very fine-grained quartz (Ø 0.05-0.3 mm) occurs as euhedral-subhedral grains in the groundmass and as drop-shaped (drop quartz) and concave inclusions (concave quartz) in potassium feldspar ovoids and phenocrysts.

Although an abundance of fine-grained quartz occurs in some wiborgites and dark-coloured wiborgites in intergrown with potassium feldspar, this mineral generally is not present in porphyritic rapakivi varieties. On the other hand, fine-grained quartz occurs abundantly in several even-grained biotite rapakivi granites, porphyry aplites, some dark-coloured, even-grained rapakivi granites and, especially, the Jaala-Iitti hornblende rapakivi complex (Table 4).

The highest content of plagioclase (24-28 %) occurs in some dark-coloured wiborgites, dark-coloured, even-grained rapakivi granites, in grey Kymi rapakivi and in Sinkko granite (porphyritic rapakivi granite). In some pyterlites and even-grained biotite rapakivi granites plagioclase occurs only as a minor constituent (5-6 %). The composition of plagioclase varies from albite to andesine, and typically it is oligoclase. The plagioclase is generally replaced partly by sericite.

Biotite, hornblende, olivine and pyroxene and their alteration products, chlorite, grunerite and iddingsite occur, as Fe-Mg-silicates. Biotite occurs in all the rapakivi varieties but its content is very low (<7 %). Hornblende occurs as one of the main minerals (10-15 %) only in some hornblende rapakivi and dark-coloured, even-grained rapakivi samples. Besides the afore-mentioned rapakivi varieties, hornblende occurs only in wiborgites, dark-coloured wiborgites and in one pyterlite sample. Olivine (fayalite) and its alteration product, iddingsite, occur in mafic rapakivi varieties (dark-coloured, even-grained rapakivi granite (tirilite), hornblende rapakivi and dark-coloured wiborgite).

Accessory minerals contained in rapakivi varieties include fluorite, apatite, zircon, opaque (magnetite) and sericite. In addition, there occasionally occur, e.g., topaz, muscovite, carbonate and epidote.

The main textural features of different rapakivi varieties are presented in Table 4. The average grain size of the groundmass of different rapakivi granites is generally medium-coarse. Only part of the even-grained biotite rapakivi granites, hornblende rapakivi granites, porphyry aplites and quartz porphyrites are fine-grained in their groundmass.

The proportion of groundmass in the porphyritic rapakivi varieties is only 25-35 %, but in the other rapakivi varieties over 70 %. The amount of groundmass is also reflected in the frequency of occurrence of ovoids: ovoids are abundant in porphyritic rapakivi varieties, whereas in certain even-grained biotite rapakivi granites, in particular, there are hardly any. In all the samples studied that contained ovoids, they were almost always 1-6 cm in size. In only some of the dark-coloured wiborgites were there also ovoids measuring over 6 cm in diameter in abundance.

In all the rapakivi varieties, there occurs some or fairly abundant microjointing. Those samples in which, on the basis of polarization microscopic examination, microjointing does not occur are generally fine-grained in their groundmass and in addition contain an abundance of fine-grained quartz (Table 4).

Disintegration, fractures and jointings are typical of porphyritic rapakivi varieties (wiborgite, dark-coloured wiborgite, pyterlite, porphyritic rapakivi granite). Because of the many products of disintegration, which are often limited to the surface part of the bedrock (to a depth of 1.0-1.5 m), the sampling of these rocks for laboratory tests is quite difficult. Less disintegration takes place in even-grained biotite rapakivi, grey Kymi rapakivi, porphyry aplite and quartz porphyry dykes. Usually the disintegrated crust of these rapakivi varieties is only 0.5-1.0 cm.

Little disintegration of the hornblende rapakivi is to be observed in either of the large areas investigated: the Lappeenranta and Jaala-Iitti areas. It is typical of the dark-coloured, even-grained rapakivi that the bedrock is disintegrated in its surface parts (at least down to a depth of 1 m) at all the observaton sites. So sampling for the laboratory studies is often very difficult.

4.2.2 Wiborgite

Wiborgite is the commonest rapakivi variety in the Wiborg batholith (Table 2). It characteristically contains an abundance of potassium feldspar ovoids surrounded by plagioclase mantles. Generally, the diameter of the ovoids is 1-6 cm, and large ovoids (over 8 cm) are rare (Fig. 3).

Because of the hematite pigment contained in the potassium feldspar ovoids, the dominant colour of the wiborgites varies from light brown to reddish brown. Occasionally, as in the Ylämaa area, the colour of the wiborgite ranges from light grey to light brown.

The wiborgite samples studied (16 pcs) are notably similar in mineral composition and in the proportion of their groundmass. On the other hand, they differ from each other in the grain size of their groundmass, the quantity of fine-grained quartz as well as their microjointing and disintegration (Tables 3 and 4).

Typically, the minerals of wiborgites have smooth or roundish grain boundaries. Besides, in half the wiborgites studied, euhedral quartz and also large subhedral to anhedral biotite and hornblende grains (Ø 3-10 mm) occur as groups and bands around the ovoids (samples 6-10, 13-15). In the whole investigation area, over 90 % of the wiborgitic bedrock exhibits the texture described.

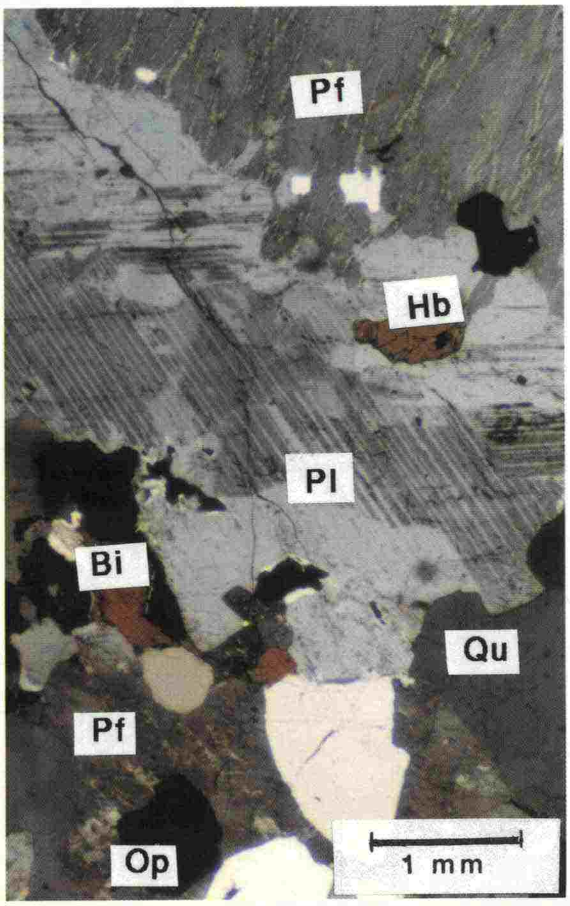
*Table 3. The mineral composition of the different rapakivi varieties studied. In porphyritic rapakivi granite, the mineral composition of samples Nos. 26.1 and 29 is presented separately. Pf= Potassium feldspar; Qu= Quartz; Pl= Plagioclase; Bi= Biotite; Hb= Hornblende; Ol=Olivine;Py=Pyroxene; Ch= Chlorite; Gr= Grunerite; Id= Iddingsite. * = mineral present in every samples; (*) = mineral present in some samples.*

Rapakivi variety	Proportionate amounts (%)									
	Pf	Qu	Pl	Bi	Hb	Ol	Py	Ch	Gr	Id
Wiborgite	46-55	21-28	15-20	2-4	4-6	-	-	(*)	(*)	(*)
Dark-coloured wiborgite	40-47	25-29	19-27	1-2	6-9	(*)	-	*	*	*
Pyterlite	59-65	25-33	6-12	2-4	(*)	-	-	*	-	-
Porphyritic	53-59	22-30	9-16	3-7	-	-	-	*	-	-
rapakivi (26.1)	45	40	10	4						
granite (29)	35	31	28	6	-	-	-	*	-	-
Even-grained biotite rapakivi	49-61	33-40	5-11	2-6	-	-	-	*	-	-
Grey Kymi rapakivi	35	29	28	3	-	-	-	-	-	-
Porphyry aplite	47-53	30-36	10-13	5	-	-	-	*	-	-
Quartz porphyry	34	58	6	2	-	-	-	*	-	-
Hornblende rapakivi	32-43	27-34	10-19	2-5	8-15	(*)	(*)	*	(*)	(*)
Dark-coloured, even-grained rapakivi (tirilite)	34-43	22-28	18-27	1-2	9-14	*	(*)	*	*	*

Table 4. The most important textural features of different rapakivi varieties. (X) = ovoids are few or occasionally present.

Rapakivi variety and observation site (Fig. 1 on page 13)	GROUNDMASS Grain size (mm)			Proportion (%)		OVOIDS (Ø cm)		QUARTZ Abundant (Ø <1.0 mm)	MICROJOINTING			
	<1	1-5	>5	25-35	>70	1-6	>6		No	Few	Rich	Very rich
1. WIBORGITE:												
A. 1, 4-7,10-13		X		X		X				X		
B. 8, 9		X		X		X					X	
C. 14, 15			X	X		X				X		
D. 2, 3, 16		X		X		X		X		X		
2. DARK-COLOURED WIBORGITE:												
A. 17.1-18.2		X		X		X	X	X		X		
B. 19, 20			X	X		X					X	
3. PYTERLITE:												
A. 21-25			X	X		X					X	
4. PORPHYRITIC RAPAKIVI GRANITE:												
A. 27, 28			X	X		X					X	
B. 26.2, 29			X	X		X					X	
C. 26.1		X		X		X		X	X			
5. EVEN-GRAINED BIOTITE RAPAKIVI:												
A. 31.2, 38, 42, 46		X			X	(X)				X		
B. 34.2		X			X	(X)					X	
C. 30, 32-34, 1, 40, 43		X			X	(X)		X		X		
D. 35, 44, 45		X			X	(X)		X			X	
E. 36, 39, 41			X		X					X		
F. 31.1, 37	X				X			X	X			
6. GREY KYMI RAPAKIVI:												
A. 47		X			X					X		
7. PORPHYRY APLITE:												
A. 64, 65, 67	X				X	X		X		X		
B. 66	X				X	X		X	X			
8. QUARTZ PORPHYRY:												
A. 68	X				X			X	X			
9. HORNBLENDE RAPAKIVI:												
A. 48, 49.1, 50	X				X	X		X	X			
B. 49.2	X				X	X		X			X	
C. 51, 52		X			X	(X)				X		
D. 53, 54, 57		X			X	(X)				X		
E. 55			X		X	(X)				X		
F. 56		X			X	(X)					X	
10. DARK-COLOURED, EVEN-GRAINED RAPAKIVI:												
A. 58, 59, 63.1		X			X	X				X		
B. 60, 61.2		X			X	X						X
C. 61.1, 63.2		X			X	X					X	
D. 62		X			X	X		X		X		

A



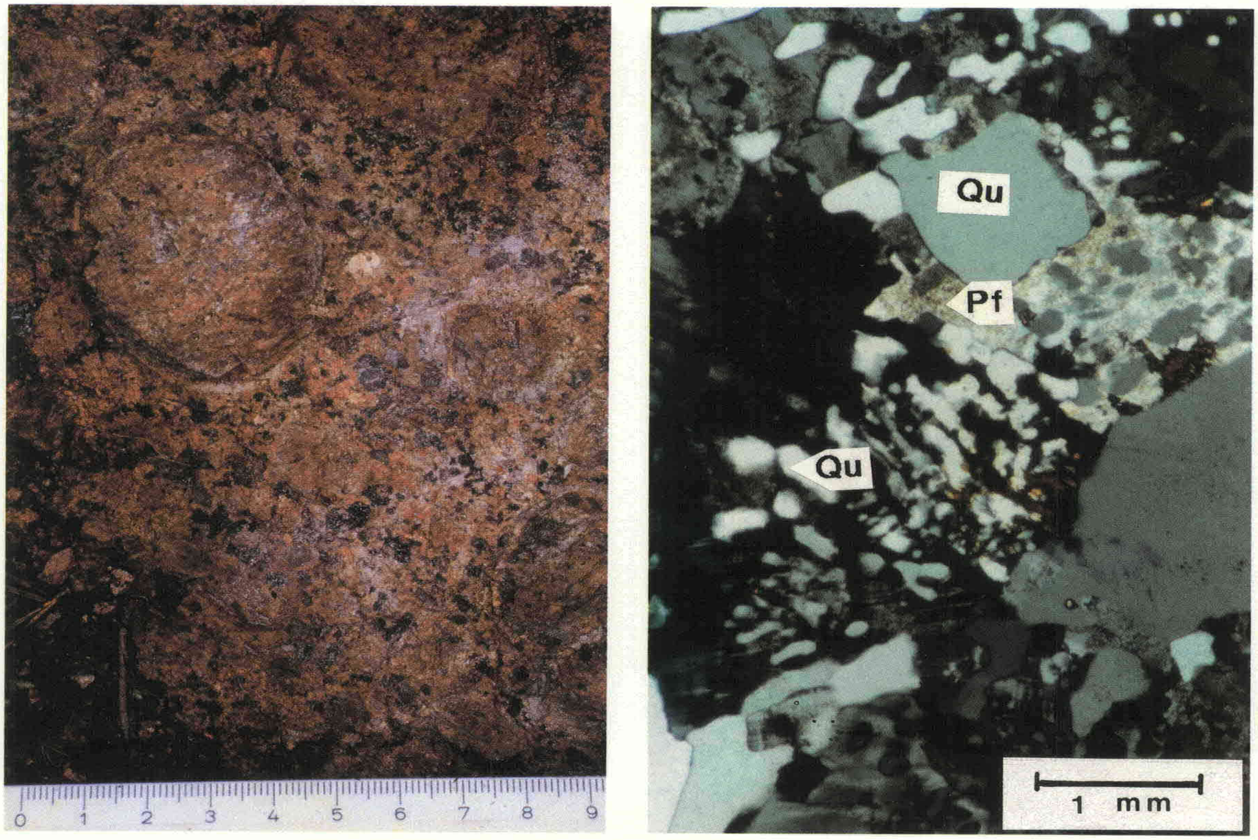
B

Fig. 3. Wiborgite at Taina, Luumäki (observation site No. 11). The photo of the bedrock surface (A) shows the occurrence of ovoids (Ø 1-3 cm), and euhedral quartz grains (Ø 5-12 mm) in the groundmass. A potassium feldspar ovoid mantled by plagioglase is shown at the top of the photomicrograph (B). The groundmass minerals are potassium feldspar (Pf), quartz (Qu), plagioclase (Pl), hornblende (Hb), biotite (Bi) and opaque (Op). Crossed polars.

The groundmass in the wiborgites studied is medium-grained (Ø 1-5 mm) at all the other observation sites except in the wiborgites to the south of Ylämaa. In these wiborgites (observation sites Nos. 14 and 15), the quartz (Ø 5-15 mm), biotite and hornblende (Ø 5-30 mm) are as notable large grains in the groundmass. Only in the wiborgites of observation sites Nos. 1-4, 11, 12 and 16, the groundmass is fine- to medium-grained (Ø < 1-3 mm).

Besides potassium feldspar ovoids surrounded by a plagioclase mantle, the wiborgites often also contain unmantled ovoids. Such "pyterlitic ovoids" are common, e.g., to the south of Anjalankoski, in the area of Juurikorpi (Fig. 1, page 13, observation site No. 4). In the area of Kaipiainen (observation site No. 19), the wiborgite changes gradually to a dark-coloured wiborgite and in the Virolahti area (observation site No. 16) to porphyry aplite. However, to the north of Hamina, in the Paijärvi area (observation site No. 52), the contact between the wiborgite and hornblende rapakivi is relatively sharp and clear.

The wiborgite samples studied generally contain as inclusions in ovoids and the groundmass small amounts of fine-grained quartz (Ø 0.05-0.3 mm), which occurs as drop quartz or lenticular or worm-like quartz inclusions (micrographic texture). In the wiborgites of observation



A **B**

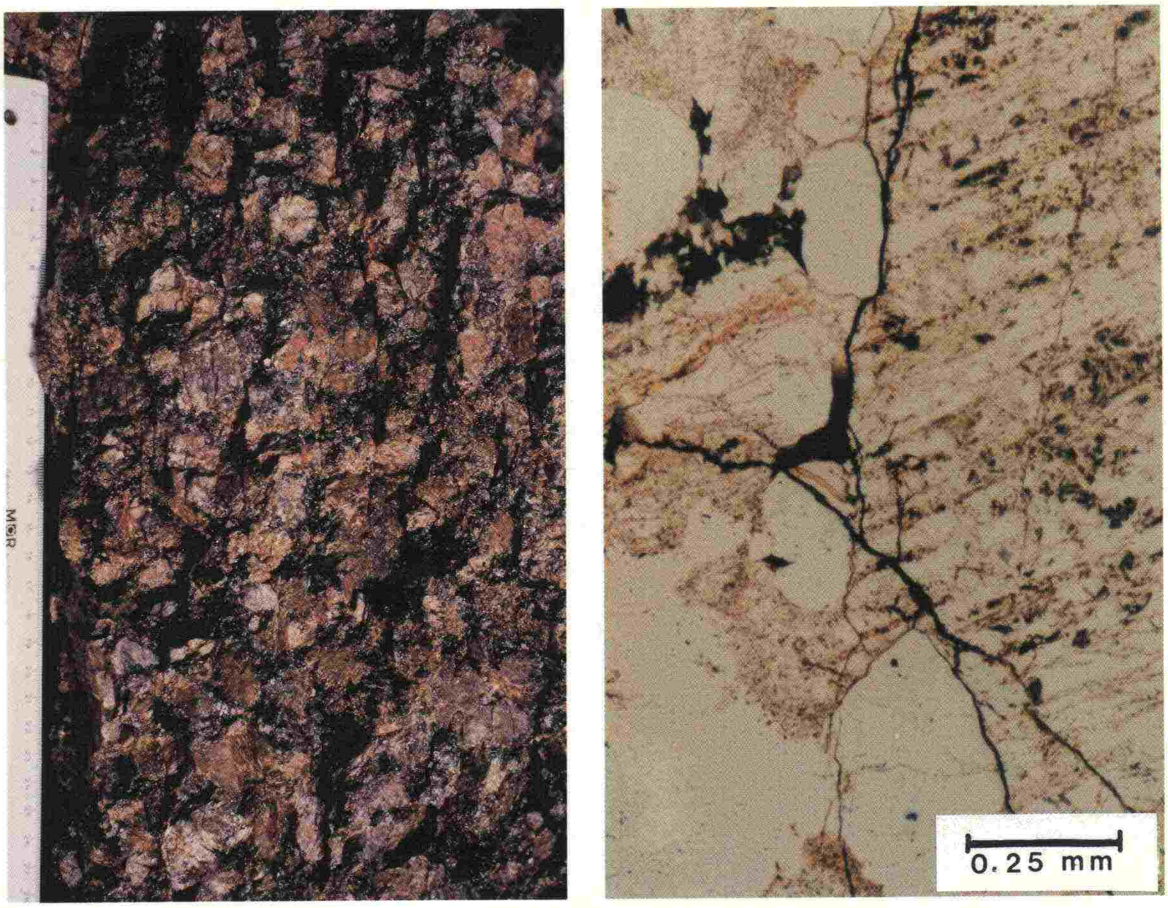
Fig. 4. Wiborgite at Vehkovuori, Kotka (observation site No. 3). The photo of the bedrock surface (A) shows ovoids situated clearly above the groundmass. The ovoids resist disintegration better than the groundmass, owing to their rich content of fine-grained quartz which is micrographically intergrown with potassium feldspar (B, photomicrograph, crossed polars). The mineral symbols are explained in Fig. 3.

sites Nos. 2, 3 and 16, fine-grained quartz is more common than usually. Fine-grained quartz occurs in some places in wiborgite ovoids distinctly more than in the groundmass (Fig. 4).

Typical of the wiborgitic bedrock, especially in the middle of the wiborgite area, to the north and west of Taavetti, there is an occurrence of disintegrated patches and horizons, fractures and jointings. To the west of Taavetti, at observation site No. 8, the FinnRA has quarried wiborgite. In this area, disintegration and moro are typical (Fig. 5A). The thin section shows very abundant microjointing and the occurrence of joints filled with mica (Fig. 5B).

4.2.3 Dark-coloured wiborgite

The proportion of dark-coloured wiborgite is about 3 % of the Wiborg batholith. It occurs mostly in the area of the western margin and also in the outer islands of the Gulf of Finland. Small occurrences are to be found, e.g, to the west of Pyhtää, in the middle area of the batholith at Kaipiainen and to the north of Hamina, as well as in the eastern part of the rapakivi area to the south of Lappeenranta.



A B

Fig. 5. Wiborgite at Aittovuori, Luumäki (observation site No. 8). Photo (A) of a quarried bedrock surface shows the loose texture of the rock, which is partly disintegrated and microjointed. The photomicrograph (B) shows abundant microjointing, which has increased the weathering rate. Parallel polars.

Like wiborgite, also dark-coloured wiborgite generally contains potassium feldspar ovoids some centimeters (1-6 cm) in diameter surrounded by a plagioclase mantle. Also the proportion of groundmass between the ovoids is generally the same. These rapakivi varieties differ most strikingly from each other with respect to their dominant colour. The dark wiborgite gets its colour from dark-coloured plagioclase and hornblende, which are more abundant in it than in ordinary wiborgite. The occurrence of olivine and iddingsite also influences the colour of the dark-coloured wiborgite (Table 3 on page 24).

The dark-coloured wiborgites studied (6 pcs) differ from each other with respect to the size of the ovoids, the grain size of the groundmass, the quantity of fine-grained quartz, the amount of microjointing and also the extent of disintegration (Table 4 on page 25).

Dark-coloured wiborgite occurring in the area of Kuusankoski - Iitti (observation sites 17 and 18) contains, besides small ovoids, also large ovoids (Ø 7-12 cm) in abundance, and the groundmass is medium-grained. In the area of Kaipiainen and especially in the Lappeenranta area (observation sites 19 and 20), almost all the ovoids measure 1-2 cm in diameter and the groundmass is medium- to coarse-grained.

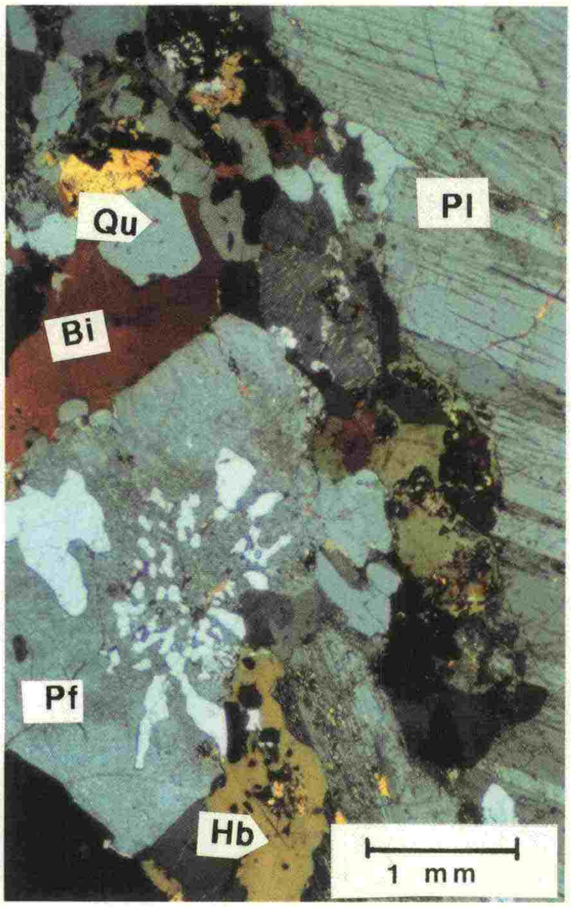


Fig. 6. Dark-coloured wiborgite at Kivistenmäki, Iitti (observation site No. 17). The photo (A) of a quarried bedrock surface clearly shows the ovoids (Ø 1-6 cm), which are lighter than the groundmass. The right side of the photomicrograph (B) presents a plagioclase mantle around the potassium feldspar ovoid. Besides quartz and feldspar, the groundmass minerals are hornblende and biotite. Crossed polars. The mineral symbols are explained in Fig. 3.

As in the wiborgites, also in the dark-coloured wiborgites, most of the minerals have straight or roundish grain boundaries, and particularly the hornblende is concentrated in rims around ovoids. Olivine has been replaced by iddingsite. Plagioclase occurs in both the ovoid structure and the groundmass as medium-sized grains (Ø 1-5 mm), and as euhedral phenocrysts measuring 1-2 cm (even 6 cm) in diameter. In the rocks of the Kaipiainen and Lappeenranta areas, the quartz and the hornblende grains are usually 5-8 mm in diameter.

Fine-grained quartz (Ø 0.05-0.3 mm) generally occurs in great abundance in the groundmass and as inclusions in the ovoids of dark-coloured wiborgites of the Kuusankoski - Iitti area. On the other hand, this quartz is lacking in dark-coloured wiborgites in the Kaipiainen and Lappeenranta areas. During thin section examination, microjointing could be clearly seen in all the samples. The most abundant microjointing appears in sample No. 20 from the Lappeenranta area.

In the Kuusankoski - Iitti area, the changing of dark-coloured wiborgite to ordinary wiborgite is not common. On the other hand, this changing is typical in the Lappeenranta and

Kaipiainen areas. The rocks of the last-mentioned areas have been classified as dark-coloured wiborgite because of their dark colouring and the occurrence of olivine and iddingsite.

4.2.4 Pyterlite

Pyterlitic rapakivi occurs in many places, and the occurrences are generally 3-20 km in diameter, throughout the Wiborg batholith area. Pyterlite accounts for about 10 % of the batholith bedrock.

The pyterlite has an abundance of ovoids 1-6 cm (gen. 2-3 cm) in diameter in the coarse-grained groundmass. Because of the high potassium feldspar content and the rich hematite pigment in it, the colour of the pyterlite is pink. The sharpest disparity between the wiborgite and the pyterlite occurs in the ovoid structure; in the pyterlites, there is no plagioclase mantle around the feldspar ovoids (Fig. 7). The pyterlitic bedrock changes into wiborgite when over 50 % of the ovoids are surrounded by a plagioclase mantle. Between the pyterlite and the porphyritic rapakivi granite, gradual change also takes place.

In the wiborgites, some variation occurs in the grain size of the groundmass and the textural features. On the other hand, the pyterlite samples studied are quite similar in their mineralogical and textural features. The pyterlite contains slightly more potassium feldspar and quartz and clearly less plagioclase and mafic minerals than does the wiborgite (Table 3 on page 24). In general, the only mafic mineral occurring in the pyterlite is biotite and its alteration product, chlorite. Hornblende occurs only in the pyterlite occurring northwest of Anjalankoski (observation site No. 21).

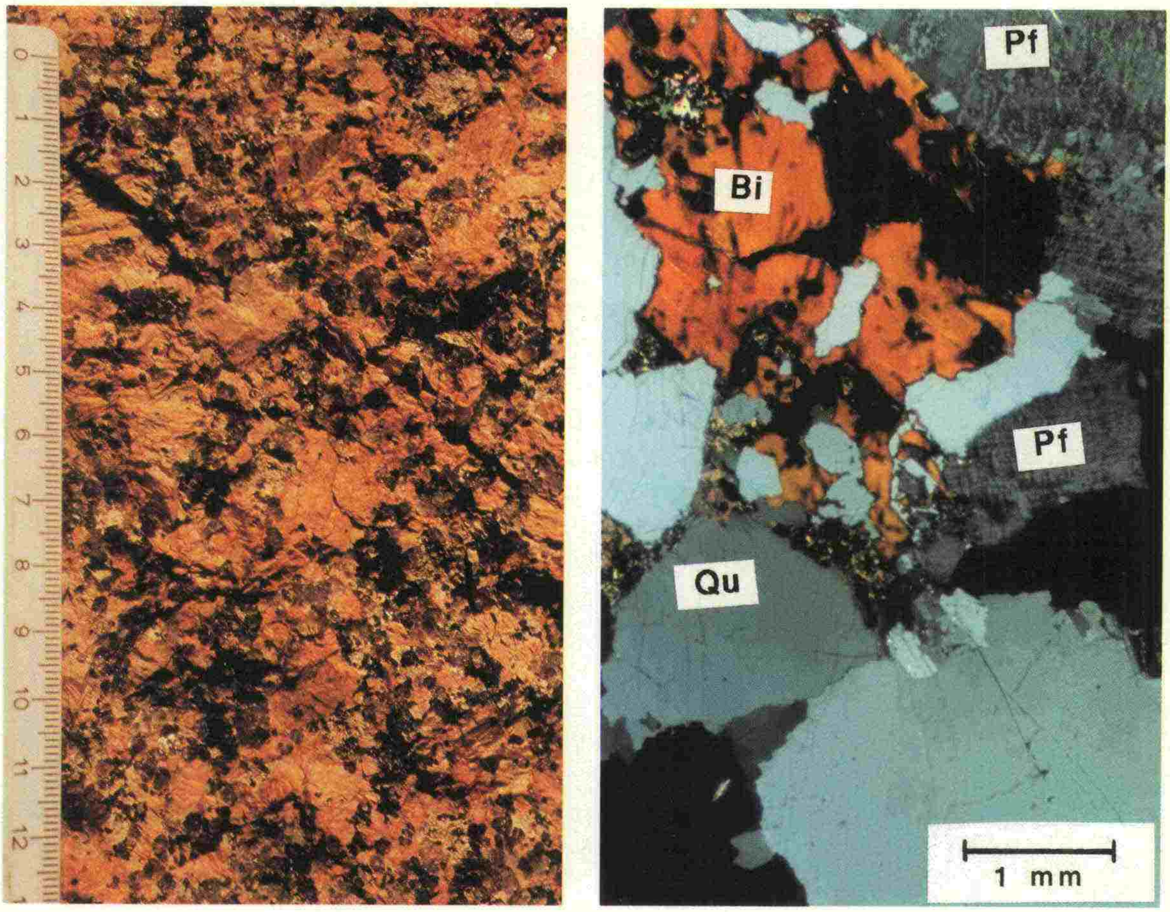
Comparing the wiborgite with the pyterlite, the grain size of the groundmass minerals of the pyterlite is larger. Especially quartz and, here and there, also biotite occur in large (even Ø up to 10-15 mm) grains. Quartz grains occur often as rims around ovoids in the pyterlitic bedrock. In the potassium feldspar ovoids of the pyterlitic samples studied, fine-grained quartz, which is commonly present in wiborgites, does not occur.

The disparity is, however, that in all the pyterlite samples studied there occurs very clear microjointing. Part of the microjoints in the pyterlite are filled with sericite, chlorite and carbonate. The weak structure of the pyterlite is due to the presence of large, euhedral minerals, the small occurrence of mafic minerals and abundant microjointing.

4.2.5 Porphyritic rapakivi granite

The porphyritic rapakivi granite content of the Wiborg batholith is only about 2 %. In connection with wiborgite and pyterlite bedrock, small amounts of porphyritic rapakivi granite often occur. This rapakivi variety occurs in larger succession in the areas of Jaala, Savitaipale and Lappeenranta.

The porphyritic rapakivi granite contains an abundance of angular phenocrysts of potassium feldspar 1-6 cm in length, situated in a medium- to coarse-grained groundmass. Besides the angular phenocrysts, here and there ovoids also occur. Generally, the colour of the porphyritic rapakivi granite is red. Only the so-called Sinkko granite is light grey (Fig. 8).



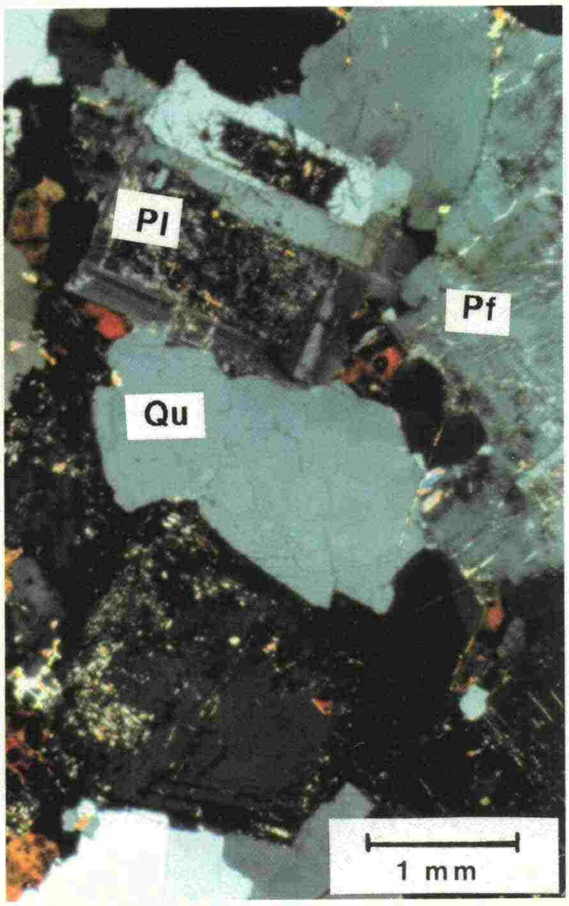
A B

Fig. 7. Pyterlite at Ristinkallio, Pyhtää (observation site No. 22). The quarried bedrock surface shows typical pyterlite features: granular and cracking texture and relatively large euhedral or rounded quartz grains (A). The photomicrograph presents a weak pyterlite texture; the large minerals are potassium feldspar, quartz and biotite. The margin of a potassium feldspar ovoid appears at the top, right (B). Crossed polars. The mineral symbols are explained in Fig. 3.

The porphyritic rapakivi granite in the Wiborg batholith area has been studied at observation sites 26-29. The mineral content of the red porphyritic rapakivi granite is similar to pyterlite. The Sinkko granite contains angular phenocrysts of plagioclase and thus it contains more plagioclase and less potassium feldspar than the other porphyritic rapakivi granites do (Table 3 on page 24).

The grain size of the quartz occurring in the porphyritic rapakivi granites is generally 5-15 mm in all the samples except those of the Sinkko granite, where it is 1-3 mm. The mafic minerals are biotite and chlorite; no hornblende is present. The weak texture of the porphyritic rapakivi granite is due to the presence of large euhedral minerals and the low content of mafic minerals. In addition, biotite occurs typically as clusters, which also partly weakens the rock texture.

At observation site No. 26, there occurs deviant porphyritic rapakivi granite because in this sample (No. 26.1) the quartz is very abundant (40 %) and there are small amounts of topaz. The quartz is mostly fine-grained (Ø 0.2-1.0 mm). This porphyritic rapakivi granite is part



A B

Fig. 8. Porphyritic rapakivi granite at Talpionmäki, Lappeenranta (observation site No. 29). Typical texture of the porphyritic rapakivi granite: large, euhedral feldspar grains (A). The photomicrograph (B) shows that the weak texture of this rapakivi variety is due to euhedral, large feldspars and quartz grains. Crossed polars. The mineral symbols are explained in Fig. 3.

of the Jaala-Iitti rapakivi complex. In the same rock cutting, there also occurs typical, coarse-grained porphyritic rapakivi granite (sample No. 26.2)

The occurrence of products of disintegration, fractures and jointings is typical in particular of the porphyritic rapakivi granite occurring to the southeast of Savitaipale (observation site No. 28), as well as in the Jaala area (observation site No. 27).

4.2.6 Even-grained biotite rapakivi

The content of even-grained biotite rapakivi amounts to only about 3 %. This rapakivi variety occurs as many small areas, especially in the western part of the batholith in the Pyhtää, Loviisa, Koskenkylä and Artjärvi regions. Further, it occurs to the north of Jaala and to the northeast of Lemi. Besides these areas, even-grained biotite rapakivi often appears as small patches, especially in the wiborgite bedrock area.

All the even-grained biotite rapakivi samples studied (17 pcs) have quite similar mineral contents. The samples studied differ from each other in the grain size of their groundmass, the quantity of ovoids and fine-grained quartz and their microjointing (Tables 3 and 4 on pages 24 and 25). The majority of the biotite rapakivi samples studied are situated close to the contact with another rapakivi variety. Many of the investigation areas are so small that they do not appear on the bedrock map drawn to a scale of 1 to 100 000.

The typical medium-grained biotite rapakivi consists mainly of euhedral feldspar and quartz grains. The same minerals often occur in the rock in small amounts as larger phenocrysts (Ø 5-10 mm). The biotite occurs often as clusters (Ø 1-3 mm). Microjointing occurs clearly but it is not abundant (Table 4, variety 5A). Variety 5B is also a typical medium-grained biotite rapakivi, but in this variety there occurs abundant microjointing.

Some of the typical medium-grained biotite rapakivi samples contain fine-grained quartz (Ø 0.2-1.0 mm) in abundance, both in the groundmass and as inclusions in larger phenocrysts of potassium feldspar (variety 5C). The quartz contained in these rocks often forms micrographic textures in the groundmass. Variety 5D differs from variety 5C, that in the variety 5D occurs abundant microjointing.

Among the samples studied in three places the biotite rapakivi is coarse-grained (Table 4, variety 5E). Potassium feldspar and some of the quartz occur as coarse, euhedral grains (Ø 5-12 mm). Biotite occurs typically as clusters (Ø 2-10 mm). The occurrence of clear microjointing is typical of the coarse-grained biotite rapakivi; in some places also disintegration can be observed. In consequence of the grain size, grain shape and arrangement of grains, the rock is very weak in texture.

The fine-grained biotite rapakivi samples (Table 4, variety 5F) contains some phenocrysts of potassium feldspar and quartz (Ø 1-5 mm). The fine-grained biotite rapakivi of Artjärvi (No. 31.1) gradual change over a distance of 40 centimeters to a medium-grained biotite rapakivi (No. 31.2, variety 5A). The Pyhtää area sample (No. 37) contains an abundance of fine-grained quartz as inclusions in larger phenocrysts of potassium feldspar, forming micrographic textures.

In the areas where biotite rapakivi is present, not one, but two or three varieties are often found (observation sites Nos. 31, 32 and 34). Gradual change of different varieties takes place over a very short distance. The main difference between the biotite rapakivi varieties in these areas is in their grain size and, besides, at observation site 34 in the amount of fine-grained quartz and microjointing (Fig. 9).

4.2.7 Grey Kymi rapakivi

This rapakivi variety belongs to the youngest intrusive phases of the Wiborg batholith. Grey Kymi rapakivi occurs only to the north of Karhula (observation site No. 47, Fig. 1, page 13). The grey Kymi rapakivi differs from the other rapakivi varieties of the batholith with respect to both its mineral content and appearance. Topaz, together with abundant quartz and light feldspars, produces the characteristic light colouring of the rock. Biotite is the only mafic mineral, which often stands out, occurring as clusters, in the otherwise light rock (Fig. 10).

The middle of the grey Kymi rapakivi area is porphyritic with an even-grained marginal zone, which the present study examines more closely. Quartz, feldspars and topaz are euhedral

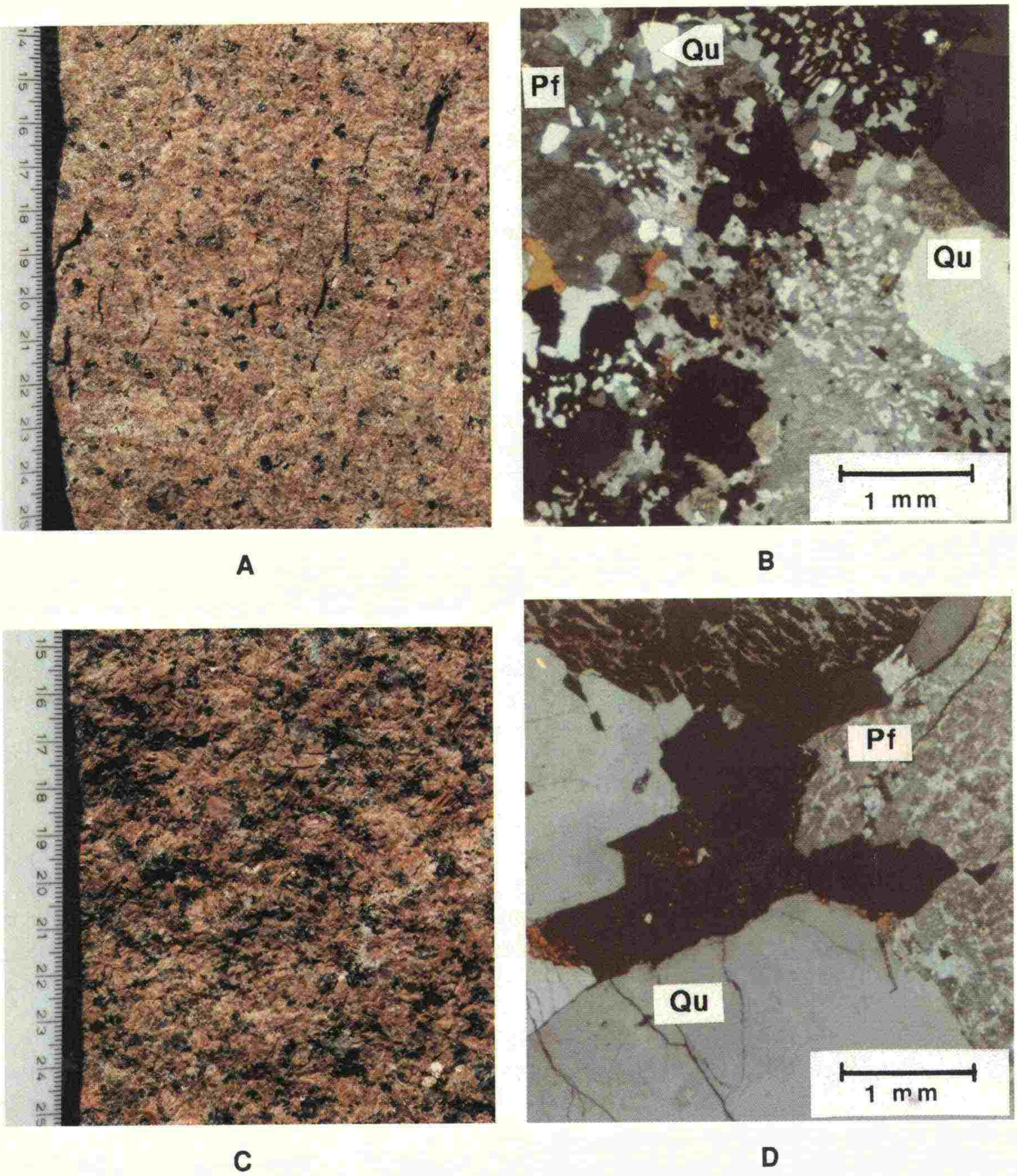
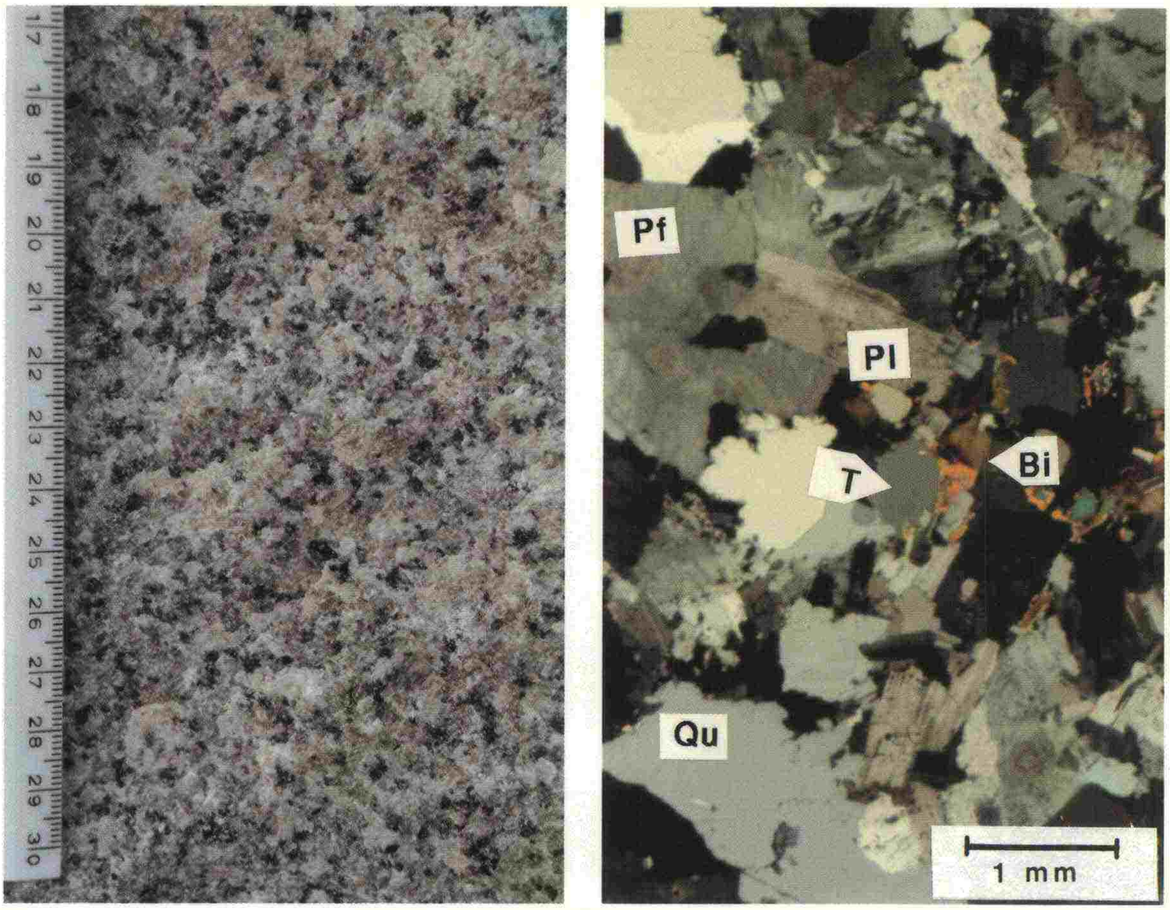


Fig. 9. Even-grained biotite rapakivi at Takamaa, Anjalankoski (observation site No. 34). The grain size of sample No. 34.1 (A) is clearly smaller than that of sample No. 34.2 (C). Photomicrograph B shows that the texture of sample No. 34.1 (A) is compact and its groundmass rich particularly in fine-grained quartz, which is micrographically intergrown with potassium feldspar. The texture of sample No. 34.2 (C), in photomicrograph D, is weak, owing to its large mineral grains and straight grain boundaries and abundant microjointing. Crossed polars. The mineral symbols are explained in Fig. 3.



A B

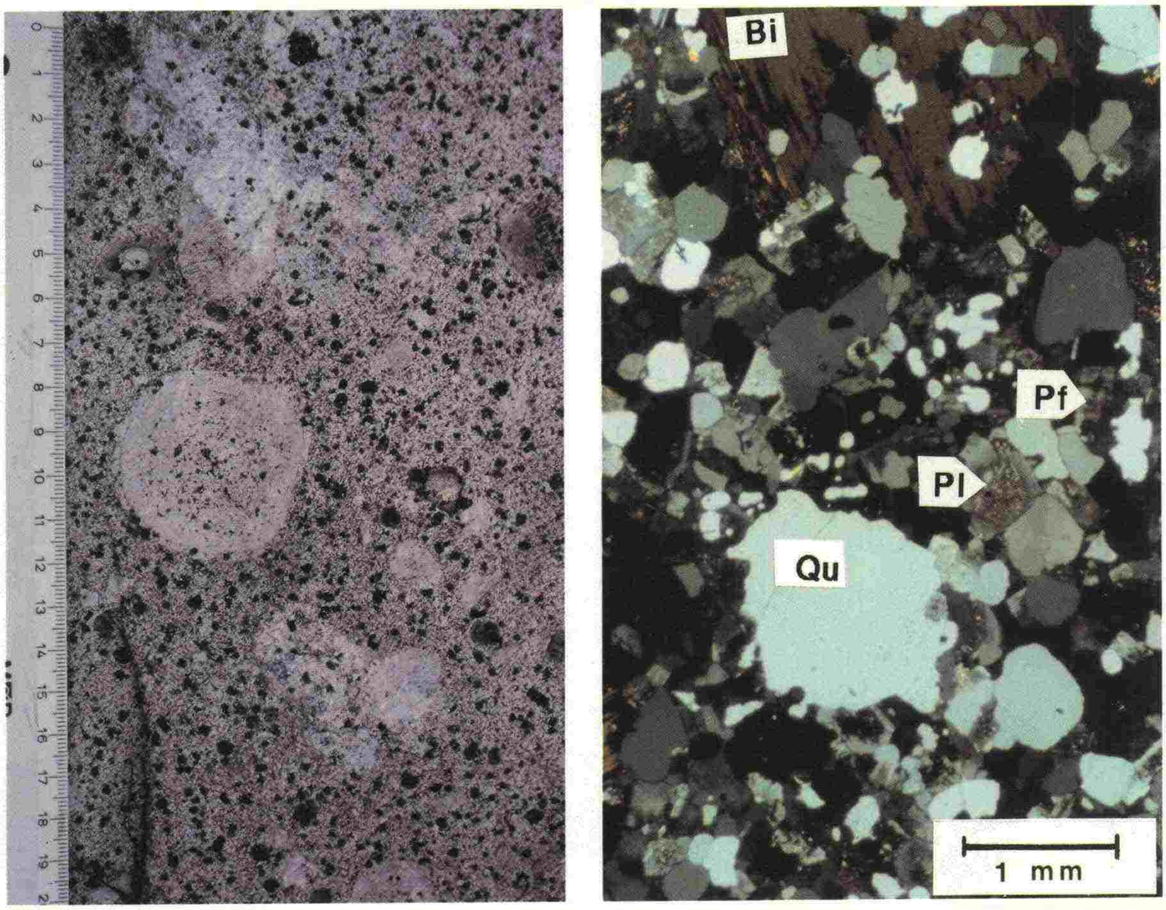
Fig. 10. Grey Kymi rapakivi at Kivimäki, Kotka (observation site No. 47). Quartz, feldspars and topaz produce the typical light tint of this rapakivi variety, where the biotite occurs as clusters (A). Photomicrograph (B) shows that, owing to the granular structure, the links between the minerals are weak. Crossed polars. The mineral symbols are explained in Fig. 3. (T= topaz).

to subhedral, even-grained (Ø 1-5 mm) minerals. Usually, only quartz occurs in small amounts as larger grains, over 5 mm in diameter. Owing to the textural features, the links between the minerals are weak.

In the area of observation site No. 47, even-grained grey Kymi rapakivi has been quarried for building stones. However, operations have been discontinued, mainly because of the too abundant jointing. As a result of the abundant jointing, the rock has also disintegrated in places.

4.2.8 Porphyry aplite

The amount of the porphyry aplite in the Wiborg batholith bedrock is under 1 %. The largest porphyry aplite occurrences are situated in the western part of the batholith in the Loviisa, Koskenkylä and Lapinjärvi areas. In the eastern part of the batholith, this rapakivi variety occurs only in the Virolahti and Miehikkälä areas. Very small occurrences (usually under 1 hectare) can be found in, e.g, the Valkeala, Jaala and Elimäki areas.

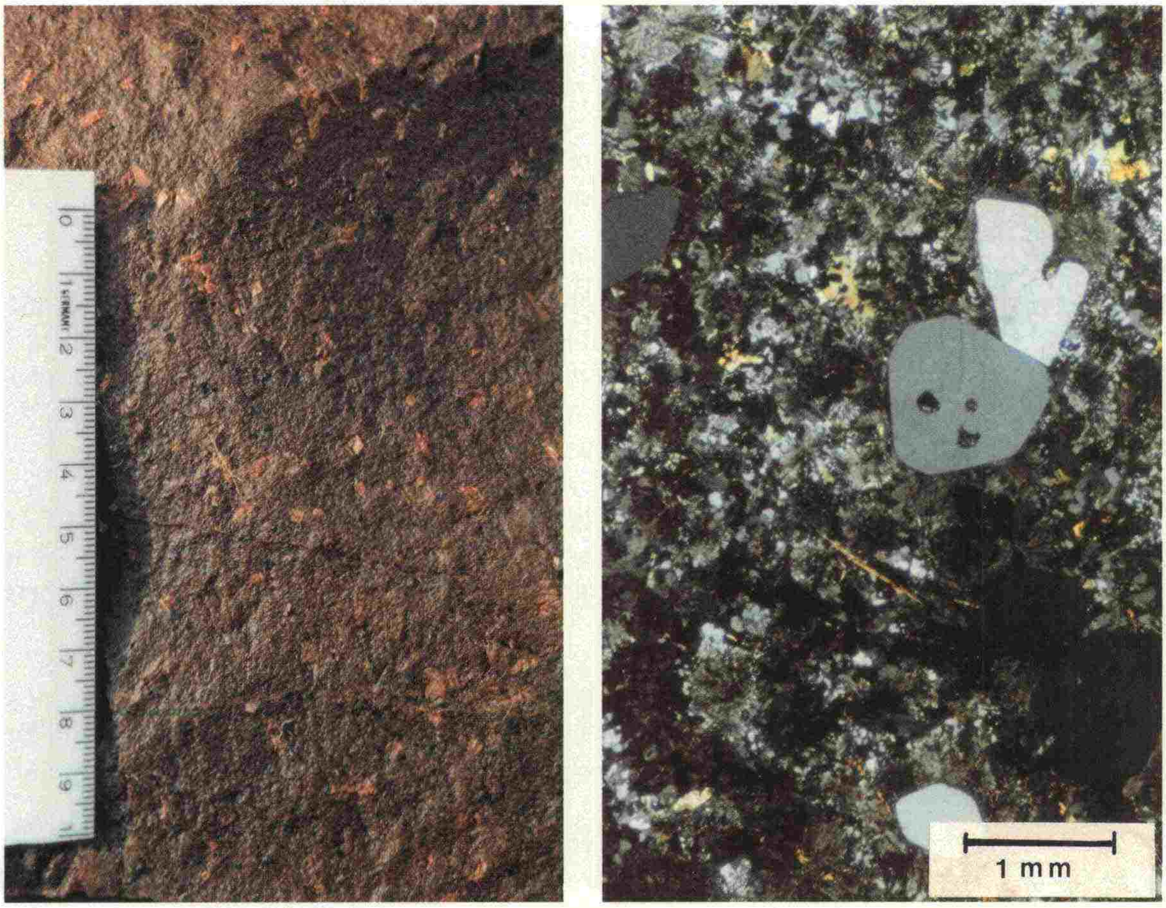


A B

Fig. 11. Porphyry aplite at Paskomäki, Virolahti (observation site No. 67). Fine-grained groundmass with dark quartz grains and light feldspar ovoids (A). Photomicrograph (B) shows that the texture of the groundmass is mechanically weak, owing to the mainly euhedral mineral grains and quite straight or smooth grain boundaries with low cohesion and low friction when stressed. Crossed polars. The mineral symbols are explained in Fig. 3.

In the present study, porphyry aplite has been investigated at observation sites Nos. 64-67 (Fig.1, page 13), of which only at site 67 the area of porphyry aplite is over 1 hectare. The porphyry aplite generally contains wiborgitic ovoids (Ø 2-3 cm) here and there; and phenocrysts measuring 2-10 mm in diameter (feldspars, quartz, biotite) occur in the fine-grained, granular groundmass (Fig. 11). The mineral content of the porphyry aplite corresponds to that of even-grained biotite rapakivi (Table 3 on page 24).

Quartz occurs both in the groundmass (Ø 0.3-1.0 mm) and as phenocrysts. Particularly in the Elimäki area (observation site No. 66), also quartz (Ø 0.05-0.3 mm) occur in abundance as inclusions in potassium feldspar grains. At all the observation sites, the porphyry aplite bedrock undergoes gradual change with the surrounding bedrock. At observation site No. 67 in the Virolahti area, the gradual change of porphyry aplite to wiborgite occurs over a distance of five meters.



A **B**

Fig. 12. Quartz porphyry at Kärenkulma, Hamina (observation site No. 68). Fine-grained, compact groundmass containing quartz and potassium feldspar phenocrysts (A). Photomicrograph B shows that the groundmass is rich in spherulitic textures. Crossed polars.

4.2.9 Quartz porphyry

Quartz porphyry dykes cutting the Wiborg batholith occur to the northwest of Hamina and to the southeast in the islands of the Gulf of Finland. The quartz porphyry dyke at observation site No. 68 in the Hamina area is vertical and measures 1-4 m in breadth. The colour of the rock is brownish red (Fig. 12). The grain size of the groundmass is fine (Ø < 0.5 mm), and it consists mainly of quartz and feldspars (Tables 3 and 4).

4.2.10 Hornblende rapakivi

The hornblende rapakivi content of the Wiborg batholith bedrock is about 4 %. This rapakivi variety occurs in larger areas to the south of Lappeenranta, in the Jaala-Iitti area and in the Haapasaari islands. The colour of the typical hornblende rapakivi is brownish red, though in the Haapasaari islands the rock is greyish. In all these areas, dark-coloured, even-grained rapakivi occurs together with hornblende rapakivi. Between these rapakivi varieties, gradual change can be observed.

The hornblende rapakivi occurring in the Lappeenranta area (so-called Lappeen granite) is quite homogeneous throughout the area (Tables 3 and 4 on pages 24 and 25, varieties 9D-F). The minerals are typically euhedral and medium-sized (Ø 2.5-5.0 mm), and especially feldspars and hornblende occur in small amounts as larger grains (Ø 5-15 mm). The fine-grained groundmass is almost completely lacking. In all the samples studied, some small-sized ovoids (Ø 1-2 cm) occur. Quartz and feldspars occur typically as inclusions in the large hornblende and biotite grains (Fig. 13).

In the Lappeenranta area (observation site No. 55), the hornblende rapakivi is coarse-grained (Ø 5-7 mm) and the plagioclase in it is strongly replaced by sericite. Products of disintegration and clear microjointing occur only in observation site No. 56. A total alteration of minerals has taken place - plagioclase is replaced by sericite, hornblende by biotite, biotite by chlorite, while olivine occurs as relic.

The subvolcanic Jaala-Iitti rapakivi complex is a dyke-like intrusion body measuring 25 km in length and 2 km in width. The complex consist mainly of hornblende rapakivi, formed by mechanical and chemical mixing of mafic (diabase) and felsic (quartz-feldspar porphyry) magma (Salonsaari & Haapala 1993).

The Jaala-Iitti area is studied at observation sites Nos. 48-50 (Fig. 1). Owing to differences in their mode of generation, the bedrock of the Jaala-Iitti complex (varieties 9A-B) differs from the corresponding bedrock of the Lappeenranta area (varieties 9D-F) in both mineral content and texture (Tables 3 and 4).

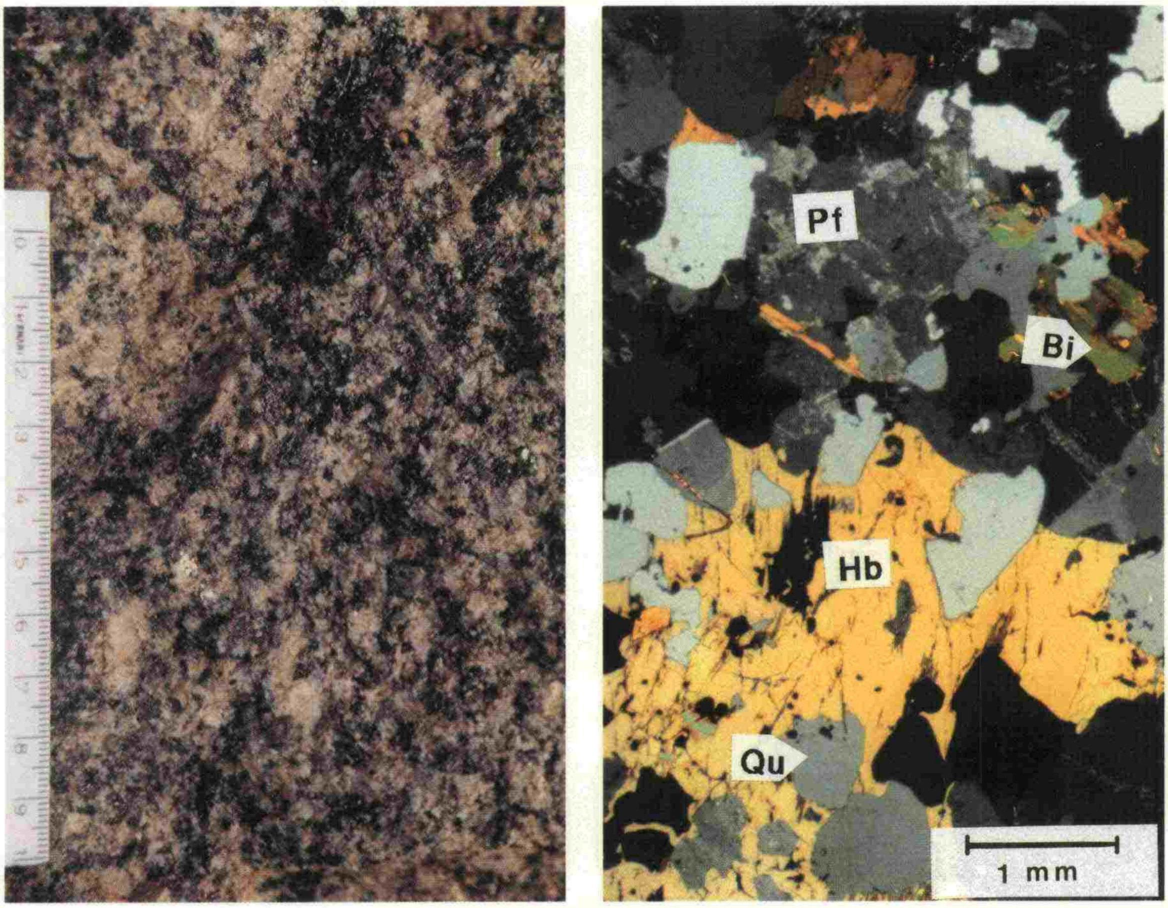
At all the observation sites in the Jaala-Iitti area, three grain size populations appear in the rock: feldspars occur as larger grains (Ø 2.5-5.0 mm), and quartz, feldspars, hornblende and biotite as medium-sized grains (Ø 0.5-2.5 mm), while the fine-grained groundmass (Ø 0.05-0.5 mm) is composed mainly of feldspars and quartz. In the groundmass, intergrowths of quartz and feldspar are common, as are also, here and there, those of hornblende and grunerite (Fig. 14).

In the second sample, No. 50.2, from observation site No. 50 in the Jaala-Iitti area, the grain size of the groundmass is coarser (Ø 0.3-0.6 mm). Minerals occurring in the groundmass are feldspars, quartz, hornblende and biotite. Although the groundmass in this sample, as also in the others, is granular, it is compact.

In the hornblende rapakivi of the Jaala-Iitti complex, the quartz, in particular, and also the feldspars, in some places, occur as inclusions in the hornblende and the biotite. Olivine and iddingsite occur as accessory minerals in samples Nos. 49.1 and 50.1.

In the bedrock of observation site No. 48, at the western end of the Jaala-Iitti complex, there occur quite numerous diabase enclaves. In this area, there is no marked disintegration, nor abundant microjointing either. However, at the east end of the complex in the Jaala area, disintegration has taken place; and here and there also pronounced microjointing has been observed under microscopic examination. In the other sample (No. 49.2) from observation site No. 49, considerable microjointing occurs as well.

In the Pyhtää and Hamina areas (Fig. 1, observation sites 51 and 52) the occurrences of hornblende rapakivi are small in extent, only a few hectares. The bedrock of these observation sites (variety 9C) resembles the hornblende rapakivi of the Lappeenranta area (variety 9D; Table 4 on page 25). In the Hamina area, the grain size of the quartz is smaller (Ø 0.5-1.5 mm) than in corresponding rocks of the Lappeenranta area.



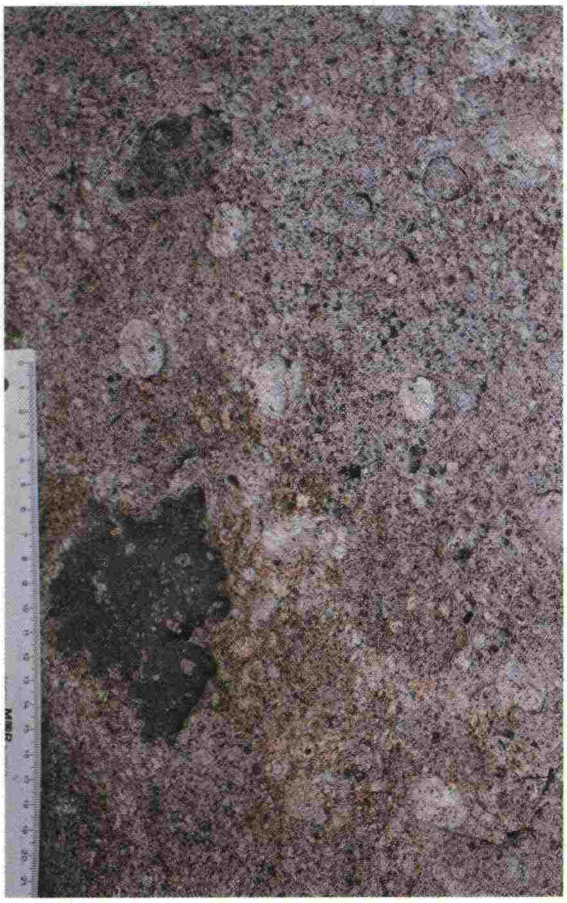
A B

Fig. 13. Hornblende rapakivi at Väinänpäänmäki, Lappeenranta (observation site No. 53). Medium-grained rock with a rich hornblende content (A). Photomicrograph B shows the granular structure, where quartz, in particular, occurs as inclusions in hornblende grains. Crossed polars. The mineral symbols are explained in Fig. 3.

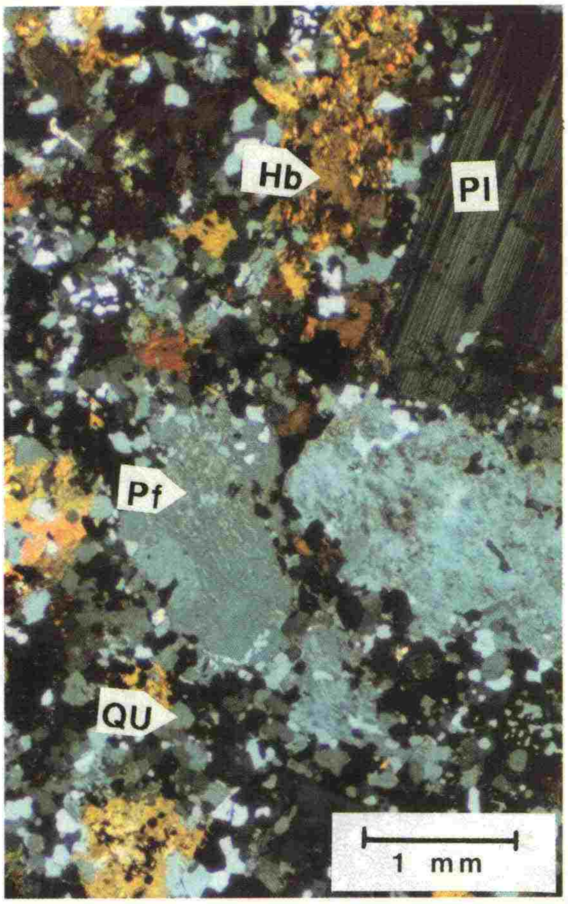
The contacts of the hornblende rapakivi with surrounding bedrock in the northern part of Hamina are relatively sharp. On both the north and south sides, the hornblende rapakivi is bounded almost in an east-west direction by wiborgite, the southern side of which is conspicuously disintegrated.

4.2.11 Dark-coloured, even-grained rapakivi (tirilite)

The content of dark-coloured, even-grained rapakivi of the batholith bedrock is under 3 %. This rapakivi variety mainly occurs only around Lappeenranta and Ylämaa in the eastern part of the Wiborg batholith, and in small amounts in connection with the hornblende rapakivi of Jaala-Iitti, as well as in the Haapasaari islands in the Gulf of Finland. The dominant colour of the dark, even-grained rapakivi, or tirilite, is dark green or dark grey. The rock contains ovoids (Ø 1-3 cm) situated far apart.



A



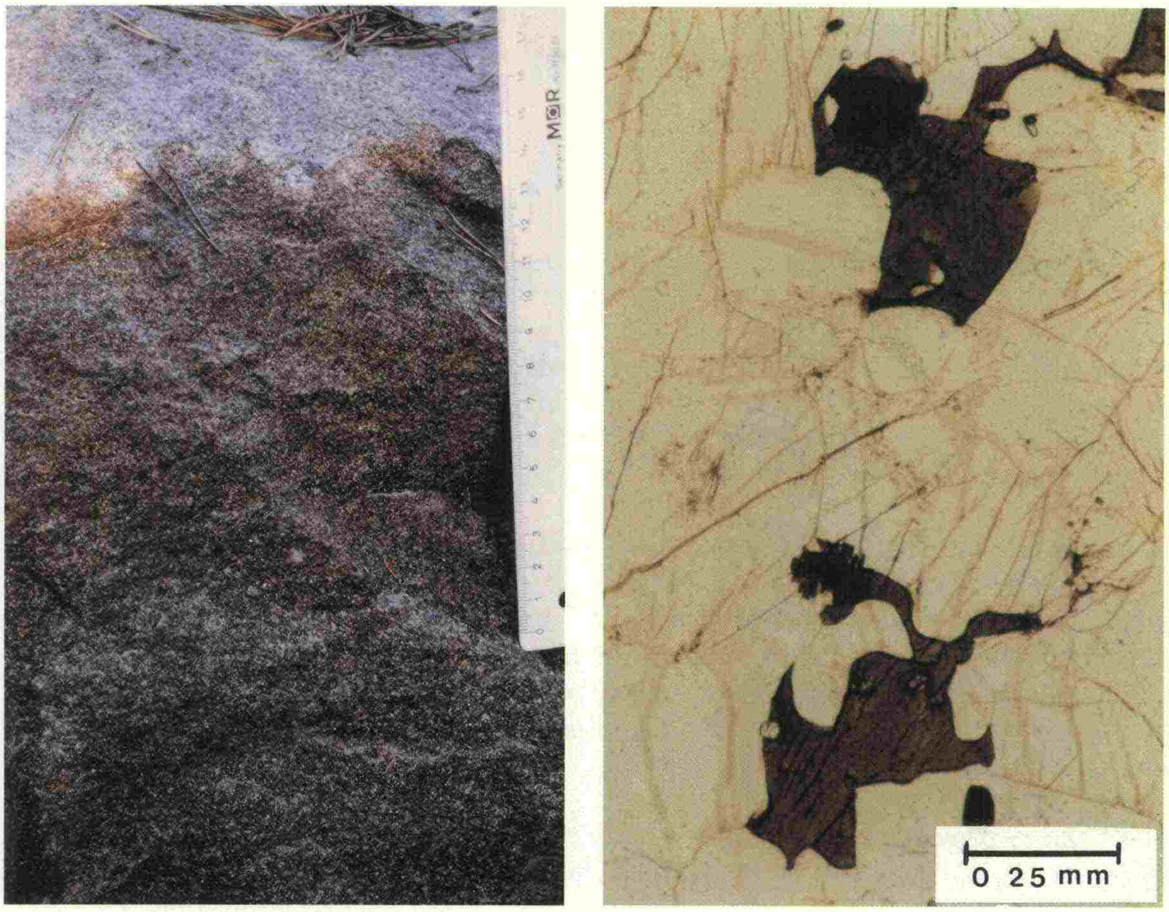
B

Fig. 14. Hornblende rapakivi at Lokonmäki, Iitti (observation site No. 48). Fine- to medium-grained groundmass with few ovoids and diabase enclaves (A). Photomicrograph B shows that, owing to the varying grain size and irregular grain boundaries, the rock looks very compact. Crossed polars. The mineral symbols are explained in Fig. 3.

Dark-coloured, even-grained rapakivi has been examined at observation sites Nos. 58-63, all of which are situated in the Lappeenranta and Ylämaa areas (Fig. 1, page 13). The rock of observation site No. 62 differs from the other samples studied by its smaller grain size (Ø 1-3 mm) and in abundance of fine-grained quartz (Ø 0.1-0.3 mm).

In the other samples, the main minerals (feldspars, quartz) are mostly medium-grained (Ø 2-5 mm), the feldspars occur far apart also as larger grains (Ø 5-12 mm) and the quartz occurs partly as small grains (Ø 0.3-1.0 mm) often also as inclusions in feldspars and hornblende. In all the samples occur hornblende, olivine and biotite as well as their alteration products grunerite, iddingsite and chlorite. From these minerals only hornblende occurs as one of the main minerals. In particular, at observation site No. 62, magnetite occurs as an abundant impregnation.

At observation site No. 62, in the Ylämaa area, and to the west of Lappeenranta (Nos. 58, 59) the partial disintegration of the tirilitic bedrock can be observed only in a thin section, but at other observation sites ocular inspection suffices. Particularly in sample No. 61.2,



A B

Fig. 15. Dark-coloured, even-grained rapakivi at Kivelä, Ylämaa (observation site No. 63). As regards its textural features, this rock looks rather compact. The upper part of the bedrock is markedly disintegrated (A). Photomicrograph B shows abundant microjointing, the mafic mineral being hornblende (Hb). Parallel polars.

microjointing is quite abundant and the cracks are partly filled (sericite, carbonate). In the parallel sample, No. 61.1, from the same observation site, considerably less microjointing occurs, although it has been taken at a horizontal distance of only 10 m.

Fig. 15 A shows that the rock is clearly disintegrated in its surface part down to a depth of 20 cm. Fig. 15 B very clearly shows abundant microjointing, which obviously has furthered disintegration. Photomicrograph 15 B represents a rock sampled in the bedrock surface to a depth of 0.5 m.

5 TECHNICAL CHARACTERISTICS OF THE ROCK MATERIALS USED IN ROAD CONSTRUCTION

5.1 General

In Finland roads are constructed in two parts: the subgrade and the pavement structure. By the subgrade is meant the fill in the embankments and the shaped and compacted natural ground along the cuts. The pavement structure consists of the lower part, which includes a filter course and a sub-base, and the upper part, which includes the base course and the pavement. The top layer of the pavement is known as the wearing course (Fig. 16). The main function of the pavement structure is to receive the load applied by traffic and distribute it to the subgrade (Hartikainen 1990).

In the procedure followed by the FinnRA in dimensioning pavement structures, account is taken, as contributing factors, of the volume and weight of the traffic, the quality of the subgrade and the bearing capacity and other properties of the structural courses in the pavement structure. The points of departure of the bearing capacity dimensioning are the target bearing capacity, the bearing capacity of the subgrade and the quality of the building material. The thicknesses of the structural courses can be thereby determined (Tie- ja vesirakennushallitus 1970, 1985).

The bearing capacity aimed at depends on the traffic volume, or the number of loading cycles, which is calculated on the basis of the dimensioning period and the volume and composition of heavy traffic. The width of the road is also taken into account. The traffic volume prevailing ten years after the opening of the road is used in the dimensioning. The number of loading cycles has a bearing on the selection of the type of pavement, its thickness and thereby also the dimensioning and dimensioning time of the unbound course. For example: a road paved with bituminous concrete ought to last 20 years before the pavement structure would require renewal (Tie- ja vesirakennushallitus 1970, 1985).

As late as the decade of the 1980s, ruts on main roads were levelled by repaving, with the result that the total thickness of the surfacing often exceeded 200 mm. Nowadays, a rutted road is levelled by milling action, as a result of which the total thickness of the surfacing layer is no longer so noticeable.

The main function of the wearing course (= the topmost pavement layer) is to prevent water from seeping down into lower structural courses as well as to provide traffic with an even, safe and durable road surface. Bitumen and crushed rock are the main components in the mixture, and crushed rock composes the bulk of the material (over 90 % by weight).

Asphalt pavements undergo wear mainly from studded tires; and, on the basis of the findings made by the ASTO project (Saarela 1992), the quality of the rock has a highly significant effect on the resistance of pavements to wear. The quality of the rock is determined mainly on the basis of laboratory tests (Tables 5 and 6), and the requirements placed on the rock used for any given road pavement depend on the traffic volume on the said road (Table 7).

The present study has investigated the suitability of the rapakivi granites of the Wiborg batholith as the rock aggregate for the wearing course of roads.

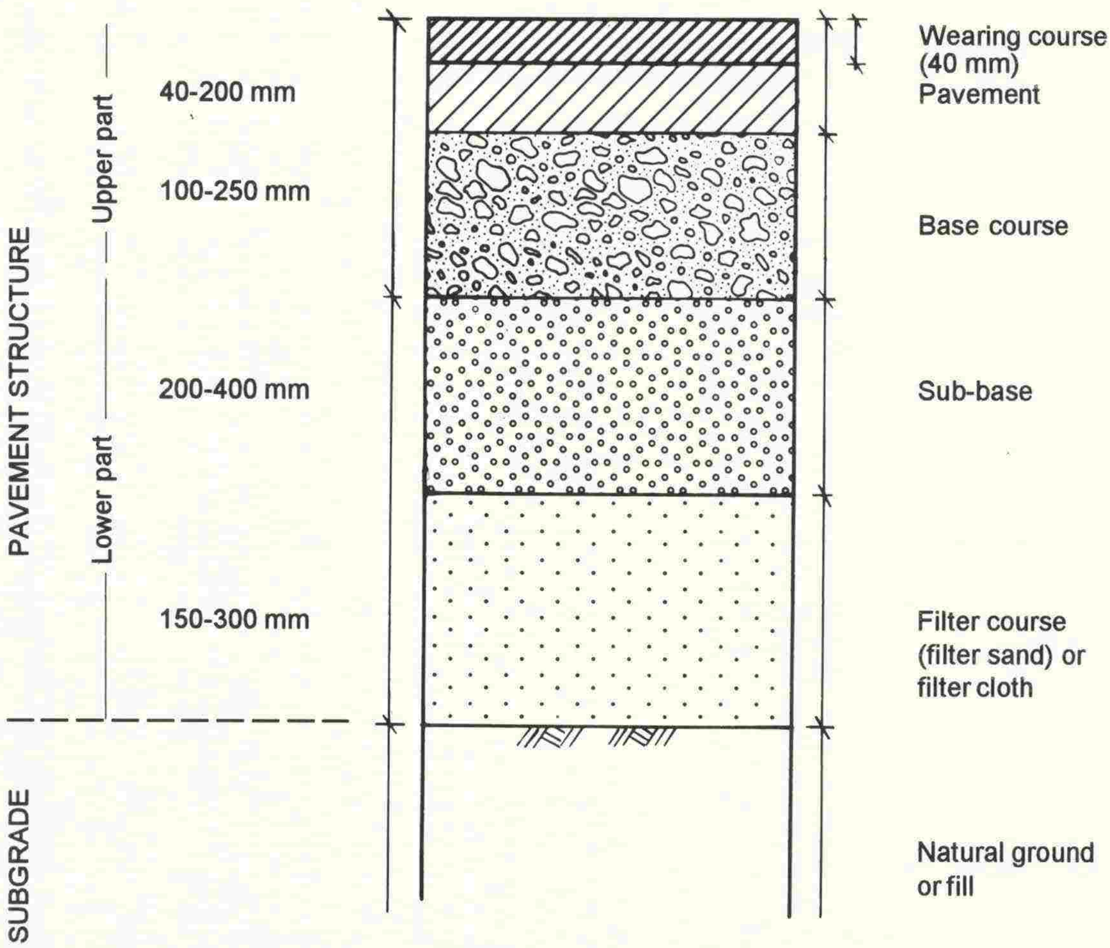


Fig. 16. Terms used for the structural courses of a road, and the general minimum thicknesses of the courses (Tie- ja vesirakennushallitus 1985).

During recent years, the requirements laid down for rock materials for asphalt pavements in FinnRA's specifications have changed almost every year. In the work instructions for asphalt pavements issued in 1987 (Tie- ja vesirakennushallitus 1987), the strength of the rock materials for asphalt pavements was defined by Swedish impact and Los Angeles tests (Table 5E); in 1988 (Tie- ja vesirakennushallitus 1988) by Swedish impact, Los Angeles and abrasion tests (Table 5D); in 1991 (Tielaitos 1991a) by point-load, abrasion, Swedish impact and Los Angeles tests (Table 5C); in FinnRA's 1993 instructions regarding rock materials testing methods (Tielaitos 1993a) involved point-load, abrasion and Nordic ball-mill tests (Table 5B); and in the 1994 specifications for crushing (Tielaitos 1993b) by point-load and Nordic ball-mill tests (Table 5A).

The classification used in FinnRA's work specifications has also changed. In this study, the same classification has been used in all the work specifications, the original, comparable strength classification of which is given in parentheses (Tables 5A-E).

Table 5. The strength classes and the quality classification of rock materials in the years 1987-1994. The original strength classification is given in parentheses.

5A. 1994 (Tielaitos 1993b):

Strength class		Point-load strength index	Nordic ball-mill value
I	(IA)	≥ 13	≤ 7
II	(IB)	≥ 10	≤ 11
III	(IC)	≥ 8	≤ 14
IV	(ID)	≥ 6	≤ 17
V	(II)	≥ 4	≤ 30

5B. 1993 (Tielaitos 1993a):

Strength class		Point-load strength index	Nordic ball-mill value	Abrasion value
I	(I)	≥ 13	≤ 7	≤ 1.5
II	(II)	≥ 10	≤ 11	≤ 2.1
III	(III)	≥ 8	≤ 14	≤ 2.6
IV	(IV)	≥ 6	≤ 17	≤ 3.1

5C. 1991 (Tielaitos 1991a):

Strength class		Point-load strength index	Abrasion value	Los Angeles value	Swedish impact value
I	(A)	≥ 13	≤ 1.8	≤ 20	≤ 18
II	(I)	≥ 11	≤ 2.3	≤ 25	≤ 22
III	(II)	≥ 9	≤ 2.8	≤ 30	≤ 26
IV	(III)	≥ 7	≤ 3.3	≤ 35	≤ 30

5D. 1988 (Tie- ja vesirakennushallitus 1988):

Strength class		Abrasion value	Los Angeles value	Swedish impact value
I	(A)	≤ 1.8	≤ 20	≤ 18
II	(I)	≤ 2.3	≤ 25	≤ 22
III	(II)	≤ 2.8	≤ 30	≤ 26
IV	(III)		≤ 35	≤ 30

5E. 1987 (Tie- ja vesirakennushallitus 1987):

Strength class		Los Angeles value	Swedish impact value
I	(A)	≤ 20	≤ 18
II	(I)	≤ 25	≤ 22
III	(II)	≤ 30	≤ 26
IV	(III)	≤ 35	≤ 30

Table 6. The shape classes and quality classification of rock materials in the years 1991 and 1994. The original shape classification of Table 6B is given in parentheses.

6A. 1994 (Tielaitos 1993b):

Shape class	Elongation (c/a)		Flakiness (b/a)		Flakiness (Euro-standard draft prEN 933-6) %
	Fraction studied, mm				
	8-12	12-16	8-12	12-16	
I	≤2.5	≤2.3	≤1.5	≤1.4	≤10
II	≤2.6	≤2.4	≤1.7	≤1.6	≤15
III	≤2.7	≤2.5	≤1.8	≤1.7	≤20
IV	≤2.9	≤2.7	≤1.9	≤1.8	≤25

6B. 1991 (Tielaitos 1991a):

Shape class	Elongation (c/a)		Flakiness (b/a)	
	Fraction studied, mm			
	8-12	12-16	8-12	12-16
I (A)	≤2.5	≤2.25	≤1.5	≤1.4
II (I)	≤2.5	≤2.25	≤1.7	≤1.6
III (II)	≤2.7	≤2.45	≤1.8	≤1.7
IV (III)	≤2.9	≤2.65	≤1.9	≤1.8

Table 7. The minimum quality classes of the rock materials used in asphalt pavements in the years 1992 and 1994.

7A. 1994 (Tielaitos 1994):

Asphalt pavement / surface treatment*	STRENGTH CLASS / SHAPE CLASS				
	Average daily traffic volume (ADT automobiles)				
	<500	500-1500	1500-2500	2500-5000	>5000
AC,GAC,SMA,GA	V / III	IV/ III	III/ III	II / II	I / I
BAC	V / III	V / III	V / III	IV/ III	III/ III
SA,OG	V / III	IV/ III	III/ III		
SIP*	V / III	IV/ II	III/ II	II / I	I / I
SOP*	V / III				

7B. 1992 (Tielaitos 1992):

Asphalt pavement / surface treatment*	STRENGTH CLASS / FORM CLASS			
	Average daily traffic volume (ADT automobiles)			
	<1000	1000-5000	5001-10 000	>10 000
AC,GAC,SMA,GA	IV/ IV	III/ III	II / III	I / III
BAC	IV/ IV	IV/ IV	IV/ IV	IV/ IV
SA,OG	IV/ IV	III/ III		
SIP*	III/ III	II / II	I / I	
SOP*	IV/ IV			

AC= asphalt concrete; GAC= gap-graded asphalt; SMA= stone mastic asphalt; GA= guss asphalt; BAC= base course asphalt concrete; SA= soft asphalt; OG= oil gravel; SIP= surface dressing with chippings; SOP= surface dressing of a gravel road. Appendix 1 explains the suitability of these asphalt types for different applications.

The classification class of Table 5E is determined by the weakest property. In Table 5D, if two of three properties determine the rock material as belonging to the same quality class, that will be the dominant class. If all three quality classes determine the rock material as belonging to different quality classes, the middle one is determined to be the quality class of this particular rock material.

The quality class of Table 5C is determined in the first place by the point-load strength index and the abrasion value, and then by the weakest property. If the point-load strength index is not determined, the quality class must be determined by the abrasion, Los Angeles and Swedish impact values. The quality class is determined as in Table 5D.

The quality classes of Tables 5B and 5A are determined by the weakest property. According to the 1994 crushing instructions (Table 5A), the strength class of rock aggregate for asphalt pavement is determined solely by the Nordic ball-mill test value; but when the rock material is crushed from blasted rock, the point-load strength index of the raw material is also determined (Tielaitos 1993b).

FinnRA's 1994 instructions for crushing (Tielaitos 1993b) also give the changed classifications of the shape classes, the classification and definition methods applied to rock aggregates differing from the instructions used earlier (Tables 6A and 6B). The shape class of the rock aggregate is defined by the elongation or the flakiness index of the material, depending on which gives a lower class or, alternatively, the flakiness determined by the eurostandard draft (prEN 933-6). The shape indices determined from the 8-12 mm fraction; but if the crushed material does not contain this fraction, the shape indices are determined from the 12-16 mm fraction (Tielaitos 1991a, 1993b).

The requirements relating to the rock material for any given asphalt pavement depend on the traffic volume of the road in question. Table 7 shows the minimum quality classes of rock material for pavements, based on the use of the rock material for paving purposes and on the traffic volume of the road. According to the 1994 paving instructions, when the average daily traffic volume exceeds 5000 vehicles, the strength class of the rock material shall be I. According to previous instructions (Table 7B), the corresponding average daily traffic volume was 10 000 vehicles.

The influence of the strength of the rock aggregate on the wearing resistance of the asphalt pavement is greater than that of the shape properties. So, often in practice, if the strength properties of the rock material meet the requirements of its use, slight deviations in excess of the shape class requirements (lower quality) are allowed. With regard to intention for use, lower quality requirements can also be accepted than those in Table 7 if it would be more advantageous for road construction and maintenance, and taking into account total costs, based on comparative calculations (Tielaitos 1991b).

The rocks investigated in the present study were crushed in the Central Laboratory of the Kymi Region before the laboratory tests. The crushing was done in two stages, using at the latter stage a smothered crushing (with a full crusher jaw).

The fractions of rock aggregate needed for the laboratory tests were sieved out from the final product of the laboratory crusher, from which the specific gravity, shape index, Los Angeles value, Swedish impact value, abrasion value, Nordic ball-mill value and point-load strength index were determined for each. To determine the point-load strength index, the sample cores were also drilled with the drilling machine of the Region and with a so-called minidrill apparatus.

5.2 Laboratory test results of rapakivi granite varieties and affecting petrographic factors

5.2.1 Specific gravity

The specific gravities of the rapakivi samples studied vary between 2.61 and 2.78 g/cm³ (Table 8). The small variation in specific gravities indicates that the different rapakivi varieties are nearly similar in mineral composition. Table 8 shows that the rapakivi varieties are divided into three different categories.

The average specific gravity of the most felsic rapakivi granites (pyterlite, porphyritic rapakivi granite, even-grained biotite rapakivi, porphyry aplite, grey Kymi rapakivi, quartz porphyry) is 2.63-2.65. The only mafic mineral present in these rapakivi varieties is biotite. The average specific gravity of the mafic rapakivi granites (dark-coloured wiborgite, hornblende rapakivi, dark-coloured, even-grained rapakivi) is 2.71-2.74. In these rapakivi varieties, hornblende prevails over biotite. The most common rapakivi variety of the Wiborg batholith, wiborgite, forms an intermediate type according to its specific gravity (= 2.67).

Table 8. Specific gravity distribution of the rapakivi samples studied (77 samples) according to the different rapakivi varieties.

Specific gravity (g/cm³)	1	2	3	4	5	6	7	8
2.61	-	-	2	-	-	-	-	-
2.62	-	-	4	2	-	-	-	-
2.63	2	2	6	1	1	-	-	-
2.64	2	1	3	1	-	-	1	-
2.65	-	1	3	-	2	-	-	-
2.66	-	1	1	-	3	-	-	-
2.67	-	-	-	-	4	-	1	-
2.68	1	-	-	-	3	1	-	-
2.69	-	-	-	-	1	1	-	1
2.70	-	-	-	-	1	-	1	-
2.71	-	-	-	-	1	-	3	-
2.72	-	-	-	-	-	4	3	1
2.73	-	-	-	-	-	-	2	3
2.74	-	-	-	-	-	-	-	-
2.75	-	-	-	-	-	-	1	-
2.76	-	-	-	-	-	-	-	2
2.77	-	-	-	-	-	-	-	-
2.78	-	-	-	-	-	-	-	1
average	2.64	2.64	2.63	2.63	2.67	2.71	2.73	2.74

1= pyterlite, 2= porphyritic rapakivi granite, 3= even-grained biotite rapakivi, 4= porphyry aplite, 5= wiborgite, 6= dark-coloured wiborgite, 7= hornblende rapakivi, 8= dark-coloured, even-grained rapakivi. In addition: grey Kymi rapakivi = 2.65, quartz porphyry (Hamina) = 2.65.

5.2.2 Shape index

The shape index determinations of the samples investigated in the present study are made from the 8-12 mm fraction. In Tables 9-10 are shown the results of the shape index determinations of the rapakivi samples studied and their shape classes. The shape classes are based on FinnRA's instructions shown in Table 6.

On the basis of elongation, all the porphyritic rapakivi varieties studied belong to class I, while on the basis of flakiness generally to class II. The shape class is therefore mainly II (Table 9).

The shape classes of the even-grained biotite rapakivi granites vary between classes I-IV. Most of the samples studied (14/19), however, belong to classes I-II (Table 10). The even-grained biotite rapakivi sample (No. 31.1) of shape class IV is fine-grained. The weak shape class of the rock is due to the abundant jointing property of the rock. All three coarse-grained biotite rapakivi samples (Nos. 36, 39 and 41, variety 5E) belong to the shape class I. The good shape indices of these biotite rapakivi granites (as also those of the porphyritic rapakivi varieties) are due to the even grain size of the minerals, while fine- and small-grained materials are almost completely lacking.

The four porphyry aplite samples fall when crushed between shape classes II and IV (Table 10). In the area of sample No. 66, the porphyry aplite rock is clearly jointed, which explains the weak results relating to the shape index of that sample. The weak shape index of the quartz porphyry sample is due to the abundant jointing of the rock. A very distinct vertical jointing occurs in the area of this rock dyke.

The shape classes of the crushed hornblende rapakivi granites are II-III (Table 10). The research areas Nos. 48-50 are situated in the area of the Jaala-Iitti rapakivi complex. In regard to mineralogical and textural features, the rocks of these research areas are quite similiar. Accordingly, the differences between the shape classes are probably not due to the properties of the rock itself, but possibly to the inaccuracy of the method of determining the shape index.

The dark-coloured, even-grained rapakivi granite (tirilite), rock aggregate, falls into the shape classes I-III. The rock of observation site No. 62, which, having revealed less microjointing under microscopical examination, received the weakest shape class value. This sample also has the finest grain size distribution. Its bad flakiness is probably due to the difficult crushability of the rock, owing to its strength.

The changes in FinnRA's instructions (Table 6) concerning the requirement limits of the shape indices have had no substantial effect on the shape classes of the rapakivi granite samples studied (Tables 9-10). The crushing products of the different rapakivi varieties of the Wiborg batholith fall mostly into the shape classes I-II. The unexpectedly good shape properties can be explained by the fact that the massive rocks are of uniform quality, so that their behaviour in the crushing process can be easily controlled.

5.2.3 Swedish impact value

The Los Angeles and Swedish impact tests used in the laboratory work measure mainly the impact strength of the rock aggregate. In some studies, the results yielded by these two tests proved to be quite similar; correlation coefficient r exceeds 0.90 (e.g., Lappalainen 1987; Alkio & Vuorinen 1990).

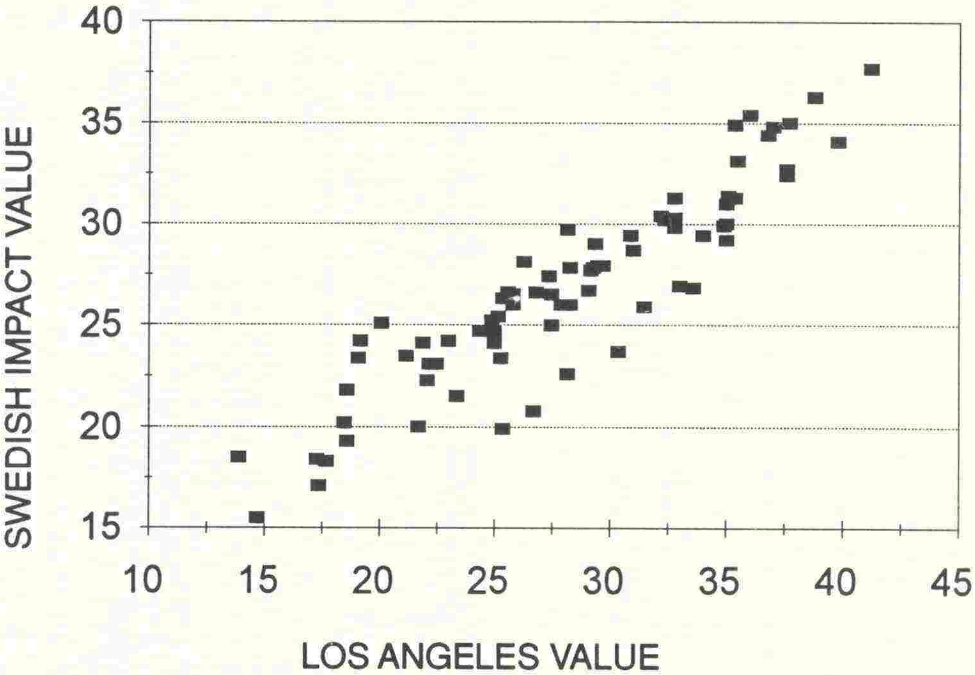


*Fig. 17. Correlation between Los Angeles and Swedish impact tests performed on rapakivi granite samples (r = 0.88***).*

Tables 11 and 12 (on pages 54 and 55) present the Los Angeles and Swedish impact test values and strength classes of the rapakivi samples studied. The results measured during this investigation by means of the Los Angeles and Swedish impact tests correlate well; r = 0.88 (Fig. 17).

When the rock samples of the Kymi Region were subjected to the Swedish impact test, it was discovered that the results yielded by parallel samples can deviate as much as over 20 % from the average. The quantity of the rock material studied using the Swedish impact test was about 0.5 kg and using the Los Angeles test about 5.0 kg. Owing to the small quantity of rock aggregate used in the Swedish impact test, it is quite sensitive to various error factors. For example, a wrong crushing method influences greatly the shape index of a rock aggregate and then also the Swedish impact value (Vallius 1992b).

It has been found that the Los Angeles and Swedish impact tests measure the same values, representing the impact strength of the rock aggregate. In other words, the criteria arrived at after the Los Angeles test for the different rapakivi varieties are valid also with regard to the results of the Swedish impact test. Since it was ascertained that the Swedish impact test is sensitive to various factors of error, the Los Angeles test is judged to be a better measurement of the impact strength of rock aggregate.

Table 9. Shape indices and shape classes of porphyritic rapakivi varieties. The shape class is based on FinnRA's directions 1991a and 1993b. If the shape class is the same, only one value is given. The textural features of different rapakivi varieties are explained in Table 4 (page 25) and the observation sites in Fig. 1 (page 13).

Rapakivi variety and observation site	Elongation (c/a)	Flakiness (b/a)	Shape class 1991a;1993b
1A Wiborgite (1)	2.1	1.6	II
1A Wiborgite (4)	2.5	1.7	II
1A Wiborgite (5)	2.3	1.6	II
1A Wiborgite (6)	2.5	1.7	II
1A Wiborgite (7)	2.3	1.6	II
1A Wiborgite (10)	2.3	1.6	II
1A Wiborgite (11)	2.5	1.6	II
1A Wiborgite (12)	2.3	1.6	II
1A Wiborgite (13)	2.2	1.6	II
1B Wiborgite (8)	2.1	1.5	I
1B Wiborgite (9)	2.3	1.6	II
1C Wiborgite (14)	2.4	1.7	II
1C Wiborgite (15)	2.2	1.5	I
1D Wiborgite (2)	2.4	1.7	II
1D Wiborgite (3)	2.3	1.5	I
1D Wiborgite (16)	2.1	1.5	I
2A Dark-coloured wiborgite (17.1)	2.2	1.6	II
2A Dark-coloured wiborgite (17.2)	2.5	1.7	II
2A Dark-coloured wiborgite (18.1)	2.4	1.6	II
2A Dark-coloured wiborgite (18.2)	2.4	1.6	II
2B Dark-coloured wiborgite (19)	2.3	1.7	II
2B Dark-coloured wiborgite (20)	2.3	1.7	II
3A Pyterlite (21)	2.2	1.5	I
3A Pyterlite (22)	2.3	1.6	II
3A Pyterlite (23)	2.2	1.5	I
3A Pyterlite (24)	2.1	1.5	I
3A Pyterlite (25)	2.2	1.6	II
4A Porphyritic rapakivi granite (27)	2.2	1.5	I
4A Porphyritic rapakivi granite (28)	2.3	1.6	II
4B Porphyritic rapakivi granite (26.2)	2.4	1.7	II
4B Porphyritic rapakivi granite (29)	2.3	1.6	II
4C Porphyritic rapakivi granite (26.1)	2.5	1.7	II

Table 10. Shape indices and shape classes of even-grained biotite rapakivi, grey Kymi rapakivi, porphyry aplite, quartz porphyry, hornblende rapakivi and dark-coloured, even-grained rapakivi (=tirilite). Explanations in Table 9.

Rapakivi variety and observation site	Elongation (c/a)	Flakiness (b/a)	Shape class 1991a;1993b
5A Even-grained biotite rapakivi (31.2)	2.5	1.7	II
5A Even-grained biotite rapakivi (38)	2.4	1.7	II
5A Even-grained biotite rapakivi (42)	2.5	1.7	II
5A Even-grained biotite rapakivi (46)	2.5	1.7	II
5B Even-grained biotite rapakivi (34.2)	2.3	1.7	II
5C Even-grained biotite rapakivi (30)	2.6	1.8	III
5C Even-grained biotite rapakivi (32)	2.3	1.6	II
5C Even-grained biotite rapakivi (33)	2.7	1.8	III
5C Even-grained biotite rapakivi (34.1)	2.3	1.7	II
5C Even-grained biotite rapakivi (40)	2.7	1.8	III
5C Even-grained biotite rapakivi (43)	2.6	1.8	III
5D Even-grained biotite rapakivi (35)	2.4	1.7	II
5D Even-grained biotite rapakivi (44)	2.2	1.6	II
5D Even-grained biotite rapakivi (45)	2.4	1.7	II
5E Even-grained biotite rapakivi (36)	2.3	1.5	I
5E Even-grained biotite rapakivi (39)	2.1	1.5	I
5E Even-grained biotite rapakivi (41)	2.1	1.4	I
5F Even-grained biotite rapakivi (31.1)	2.9	1.9	IV
5F Even-grained biotite rapakivi (37)	2.4	1.7	II
6A Grey Kymi rapakivi (47)	2.4	1.7	II
7A Porphyry aplite (64)	2.3	1.7	II
7A Porphyry aplite (65)	2.6	1.7	III;II
7A Porphyry aplite (67)	2.4	1.7	II
7B Porphyry aplite (66)	2.7	1.9	IV
8A Quartz porphyry (68)	2.7	1.8	III
9A Hornblende rapakivi (48)	2.3	1.6	II
9A Hornblende rapakivi (49.1)	2.5	1.7	II
9A Hornblende rapakivi (50.1)	2.5	1.8	III
9A Hornblende rapakivi (50.2)	2.5	1.8	III
9B Hornblende rapakivi (49.2)	2.3	1.7	II
9C Hornblende rapakivi (51)	2.2	1.6	II
9C Hornblende rapakivi (52)	2.5	1.8	III
9D Hornblende rapakivi (53)	2.2	1.6	II
9D Hornblende rapakivi (54)	2.5	1.7	II
9D Hornblende rapakivi (57)	2.6	1.7	III;II
9E Hornblende rapakivi (55)	2.4	1.7	II
9F Hornblende rapakivi (56)	2.2	1.6	II
10A Tirilite (58)	2.3	1.6	II
10A Tirilite (59)	2.5	1.7	II
10A Tirilite (63.1)	2.4	1.6	II
10B Tirilite (60)	2.4	1.5	I
10B Tirilite (61.2)	2.2	1.6	II
10C Tirilite (61.1)	2.4	1.6	II
10C Tirilite (63.2)	2.1	1.5	I
10D Tirilite (62)	2.5	1.8	III

5.2.4 Los Angeles value

Wiborgite

Of the 16 wiborgite samples put to the Los Angeles test, four are classless (= weaker than any of the class criteria), five in class IV and seven in class III (Table 11). These figures do not give an objective idea of the distribution by strength classes of different wiborgite varieties (Table 4 on page 25). The main aim of the present study was to find the most resistant rocks; and some selection was already done by sampling. Typically, according to the Los Angeles test, the wiborgites belong to the IV strength class.

The wiborgites with a medium- to coarse-grained groundmass (observation sites of Ylämaa Nos. 14 and 15, variety 1C) and the wiborgites having abundant microjointing (observation sites of Taavetti Nos. 8 and 9, variety 1B) are classless. For example, at observation site 8, where the FinnRA has quarried wiborgite for road construction material, abundant jointing occurs in the bedrock at the whole quarried depth (about 8 m), and here and there the bedrock is slightly disintegrated.

The III class wiborgite samples, according to the Los Angeles value, have fine- to medium-grained groundmass with some microjointing (observation sites 1-4, 11, 12 and 16). Besides, the wiborgites from observation sites 2, 3 and 16 (variety 1D), in particular, contain an abundance of fine-grained quartz, both in the groundmass and as inclusions in potassium feldspar ovoids.

Dark-coloured wiborgite

With regard to strength, the dark-coloured wiborgites vary, according to the Los Angeles test, between class II and classless (Table 11). The samples from Kaipiainen and Lappeenranta (observation sites 19 and 20), with abundant microjointing, belong to the IV class or are classless.

Samples Nos. 17.1 and 18.1, from the Kuusankoski area, are in the II-III strength classes. The markedly better strength qualities of the Kuusankoski area samples can be explained by their smaller grain size and distinctly slighter microjointing. The poorer strength values of the parallel samples from the Kuusankoski area (17.2 and 18.2) are due to their conspicuous microjointing.

Pyterlite

Two of the five pyterlite samples studied belong, according to the Los Angeles test, to class IV while three are classless (Table 11). The low strength values are due to the fact that the groundmass of the rock is medium- to coarse-grained and the minerals are euhedral and often as clusters. So the links between the minerals are very weak. Besides, the marked microjointing to be seen in all the samples studied also partly accounts for the low strength values.

Porphyritic rapakivi granite

The strength class according to the Los Angeles values of the porphyritic rapakivi granites studied varies from strength class II to classless. The typical mineral composition and texture of porphyritic rapakivi granite is quite similar to those of pyterlite (Tables 3 and 4 on pages 24 and 25). The strength class of these samples is IV, or they are classless (Table 11).

Rock differing from that of other porphyritic rapakivi granites occurs only at observation site No. 26. The groundmass of sample No. 26.1 contains an abundance of fine-grained quartz, and no microjointing is discernible. This sample is classified as belonging to strength class II.

Even-grained biotite rapakivi

The present research material included 19 samples of biotite rapakivi granites. According to the Los Angeles test, the strength class of biotite rapakivi varies between I and classless (Table 12). The variation in the strength classes results from the textural features and the quantity of microjointing:

- The coarse-grained and typical medium-grained biotite rapakivi varieties with abundant microjointing belong to the IV strength class or they are classless (varieties 5E and 5B, Table 4).
- The typical medium-grained biotite rapakivi variety belongs to the III strength class (variety 5A).
- The typical medium-grained biotite rapakivi variety with abundant fine-grained quartz, but also abundant microjointing, also belongs to the III strength class (variety 5D).
- The typical medium-grained biotite rapakivi variety with an abundant content of fine-grained quartz belongs to the I-II strength classes (variety 5C).
- The fine-grained biotite rapakivi variety with an abundant content of fine-grained quartz belongs to strength class I (variety 5F).

Most of the even-grained biotite rapakivi granites of the Wiborg batholith are medium-grained and, according to the Los Angeles test, belong to the III strength class. Small amounts (under 10 %) of even-grained biotite rapakivi granites differing from this variety can be found in the batholith area. These biotite rapakivis, which, owing either to their fine-grained texture or, often, to an abundant content of fine-grained (partly micrographic) quartz, belong to the I-II strength classes.

Grey Kymi rapakivi

According to the Los Angeles test, this rock belongs to the III strength class (Table 12). The grey Kymi rapakivi consists of hard, medium-grained minerals (quartz, feldspars, topaz). The lack of fine-grained mineral elements and a low content of mafic minerals, together with an even grain size, have caused the links between the minerals to be weak and have reduced the wearing resistance of the rock.

Porphyry aplite

The porphyry aplites studied belong, according to the Los Angeles test, to the I-III strength classes (Table 12). Their relatively good strength values can be explained by the fine grain size of the rock, although the groundmass has a granular texture. The porphyry aplite belonging to the I class differs from the others in that its potassium feldspar phenocrysts have a higher than usual content of fine-grained quartz. The fine-grained quartz improves the resistance to impacts of the phenocrysts.

Quartz porphyry

The very fine-grained groundmass of the rock and its subhedral minerals have caused this rock to be classified by the Los Angeles test as belonging to the I strength class (Table 12).

Table 11. Los Angeles test and Swedish impact test values and strength classes of porphyritic rapakivi varieties. The textural features of different rapakivi varieties are explained in Table 4 (page 25) and the observation sites in Fig. 1 (page 13). The strength classes and the quality classification are explained in Table 5 (page 44).

Rapakivi variety and observation site	Los Angeles value / strength class	Swedish impact value / strength class
1A Wiborgite (1)	29.1/III	26.7/IV
1A Wiborgite (4)	29.5/III	27.9/IV
1A Wiborgite (5)	31.5/IV	25.9/III
1A Wiborgite (6)	32.8/IV	30.3/-
1A Wiborgite (7)	33.6/IV	26.8/IV
1A Wiborgite (10)	33.0/IV	26.9/IV
1A Wiborgite (11)	28.1/III	26.0/III
1A Wiborgite (12)	28.3/III	27.8/IV
1A Wiborgite (13)	35.0/IV	29.2/IV
1B Wiborgite (8)	37.0/-	34.8/-
1B Wiborgite (9)	35.4/-	31.3/-
1C Wiborgite (14)	36.8/-	34.4/-
1C Wiborgite (15)	35.1/-	31.4/-
1D Wiborgite (2)	26.7/III	20.8/II
1D Wiborgite (3)	25.6/III	26.6/IV
1D Wiborgite (16)	27.5/III	26.5/IV
2A Dark-coloured wiborgite (17.1)	28.2/III	22.6/III
2A Dark-coloured wiborgite (17.2)	30.9/IV	29.4/IV
2A Dark-coloured wiborgite (18.1)	24.9/II	25.2/III
2A Dark-coloured wiborgite (18.2)	26.8/III	26.6/IV
2B Dark-coloured wiborgite (19)	32.8/IV	29.8/IV
2B Dark-coloured wiborgite (20)	37.6/-	32.4/-
3A Pyterlite (21)	35.0/IV	30.0/IV
3A Pyterlite (22)	38.8/-	36.3/-
3A Pyterlite (23)	37.7/-	35.0/-
3A Pyterlite (24)	41.2/-	37.7/-
3A Pyterlite (25)	35.0/IV	31.0/-
4A Porphyritic rapakivi granite (27)	32.8/IV	31.3/-
4A Porphyritic rapakivi granite (28)	35.5/-	33.1/-
4B Porphyritic rapakivi granite (26.2)	29.7/III	27.9/IV
4B Porphyritic rapakivi granite (29)	32.2/IV	30.4/-
4C Porphyritic rapakivi granite (26.1)	21.9/II	24.1/III

Table 12. Los Angeles test and Swedish impact test values and strength classes of even-grained biotite rapakivi, grey Kymi rapakivi, porphyry aplite, quartz porphyry, hornblende rapakivi and dark-coloured, even-grained rapakivi (=tirilite). Explanations in Table 11.

Rapakivi variety and observation site	Los Angeles value / strength class	Swedish impact value / strength class
5A Even-grained biotite rapakivi (31.2)	25.0/II	24.1/III
5A Even-grained biotite rapakivi (38)	25.8/III	26.0/III
5A Even-grained biotite rapakivi (42)	25.2/III	25.4/III
5A Even-grained biotite rapakivi (46)	27.4/III	27.4/IV
5B Even-grained biotite rapakivi (34.2)	36.0/-	35.4/-
5C Even-grained biotite rapakivi (30)	22.1/II	22.3/III
5C Even-grained biotite rapakivi (32)	21.7/II	20.0/II
5C Even-grained biotite rapakivi (33)	19.2/I	24.2/III
5C Even-grained biotite rapakivi (34.1)	22.2/II	23.1/III
5C Even-grained biotite rapakivi (40)	21.2/II	23.5/III
5C Even-grained biotite rapakivi (43)	22.5/II	23.1/III
5D Even-grained biotite rapakivi (35)	28.2/III	29.7/IV
5D Even-grained biotite rapakivi (44)	25.4/III	26.3/IV
5D Even-grained biotite rapakivi (45)	25.8/III	26.5/IV
5E Even-grained biotite rapakivi (36)	34.9/IV	29.9/IV
5E Even-grained biotite rapakivi (39)	35.4/-	34.9/-
5E Even-grained biotite rapakivi (41)	34.0/IV	29.4/IV
5F Even-grained biotite rapakivi (31.1)	14.7/I	15.5/I
5F Even-grained biotite rapakivi (37)	17.3/I	18.4/II
6A Grey Kymi rapakivi (47)	29.2/III	27.7/IV
7A Porphyry aplite (64)	20.1/II	25.1/III
7A Porphyry aplite (65)	25.3/III	23.4/III
7A Porphyry aplite (67)	25.0/II	24.7/III
7B Porphyry aplite (66)	19.1/I	23.4/III
8A Quartz porphyry (68)	13.9/I	18.5/II
9A Hornblende rapakivi (48)	17.4/I	17.1/I
9A Hornblende rapakivi (49.1)	18.5/I	20.2/II
9A Hornblende rapakivi (50.1)	18.6/I	19.3/II
9A Hornblende rapakivi (50.2)	17.7/I	18.3/II
9B Hornblende rapakivi (49.2)	29.4/III	29.0/IV
9C Hornblende rapakivi (51)	26.3/III	28.1/IV
9C Hornblende rapakivi (52)	23.0/II	24.2/III
9D Hornblende rapakivi (53)	27.9/III	26.0/III
9D Hornblende rapakivi (54)	29.3/III	27.8/IV
9D Hornblende rapakivi (57)	28.3/III	26.0/III
9E Hornblende rapakivi (55)	31.0/IV	28.7/IV
9F Hornblende rapakivi (56)	32.4/IV	30.2/-
10A Tirilite (58)	24.4/II	24.7/III
10A Tirilite (59)	25.4/III	19.9/II
10A Tirilite (63.1)	23.4/II	21.5/II
10B Tirilite (60)	39.8/-	34.1/-
10B Tirilite (61.2)	37.6/-	32.7/-
10C Tirilite (61.1)	27.5/III	25.0/III
10C Tirilite (63.2)	30.4/IV	23.7/III
10D Tirilite (62)	18.6/I	21.8/II

Hornblende rapakivi

According to the Los Angeles test, the strength class of this rapakivi varies between the I and IV classes (Table 12). The variation of the classes results from the textural features and the amount of microjointing:

- The rocks in the Jaala-Iitti complex belong into the I strength class (variety 9A, Table 4 on page 25). The good strength values can be explained by the fine- to medium-grained groundmass and the abundance of hornblende. The poorer strength class of sample No 49.2 (variety 9B) is due to its abundant microjointing.
- The rocks from the Lappeenranta area belong to the III strength class (variety 9D). The strength values below those registered in the Jaala-Iitti area can be attributed to the bigger grain size of the groundmass and the lack of fine-grained material. The inferior strength class (IV) of sample No. 55 (variety 9E) is due to its coarse grain size, and the poor strength class (IV) of sample No. 56 (variety 9F) is due to its abundant microjointing.
- The rock from the Pyhtää area belongs to the III strength class, and the one from the Hamina area to II (variety 9C). As to their textural features, these rocks are similar to the samples from the Lappeenranta area. The better strength class of the sample from the Hamina area can be explained by its content of fine-grained quartz.

Dark-coloured, even-grained rapakivi (tirilite)

The strength class of the rocks from the Lappeenranta and Ylämaa areas varies between I and classless, according to the Los Angeles test (Table 12). The differences result mostly from the amount of microjointing:

- The rocks to the south of Lappeenranta and in the Ylämaa area exhibiting very abundant microjointing are classless (variety 10B, Table 4).
- In the Ylämaa area, the rocks containing abundant microjointing are in the III-IV strength classes (variety 10C).
- The rocks to the west of Lappeenranta with slight microjointing are in the II-III strength classes and the corresponding rock in the Ylämaa area in the II strength class (variety 10A).
- In the Ylämaa area, deviating from the other samples, the rock (e.g., smaller grain size and lack of microjointing) belongs to the I strength class (variety 10D).

5.2.5 Abrasion value

In FinnRA's work instructions for the years 1988-93, the abrasion test was one of the methods described to determine the suitability of rock material as asphalt pavement material (Tables 5B-D on page 44). In the 1993 work instructions (Table 5B), the requirement limits for the abrasion test are higher than those of former work instructions. In the present study, the strength class of the rock samples is presented according to the work instructions for both 1991 and 1993.

Wiborgite

According to the 1991 work instructions, all except one of the samples studied belong as regards their abrasion value to the II strength class. On the other hand, after the 1993 work instructions, most of the samples (11/16) belong to the III strength class (Table 13).

The wiborgite samples (variety 1D, observation sites 2, 3 and 16) that have abundant fine-grained quartz in the groundmass or as inclusions in the ovoids are not, as evaluated by the abrasion test, clearly better than the other samples. Although the wiborgites are coarse-grained, their mineral content, where the main ones are hard (quartz and feldspars), explains their quite good abrasion resistance.

Dark-coloured wiborgite

The abrasion test shows that the samples from Kaipiainen and Lappeenranta (variety 2B, Table 4 on page 25), with their abundant microjointing, do not differ from other samples of dark-coloured wiborgite (variety 2A). The strength class is mainly II (1991) / III (1993). Only sample No. 17.2 belongs to a lower strength class than the others, III (1991) / IV (1993), which is due to the abundant microjointing in this rock (Table 13).

The dark-coloured wiborgites contain more mafic minerals than do the ordinary wiborgites, especially hornblende. Although the abrasion durability of pure mafic minerals is not so good as, e.g., that of the feldspars, there are no differences in the abrasion values between these two rapakivi varieties.

Pyterlite

The pyterlite samples studied belong, according to the abrasion test, mainly to the II strength class (Table 13). Their almost total lack of mafic minerals and the composition of their hard minerals explain the good abrasion qualities.

The abrasion test is sensitive for extra large grains of exceptionally wearing resistant minerals. For example, a problem was caused in one sample plate by the presence of one large quartz grain, which caused distorted results.

Porphyritic rapakivi granite

The samples of this rapakivi variety belong, according to the abrasion test, typically to the II strength class (1991) / III (1993). Sample No. 28 was taken from a rock cutting. The weaker abrasion value of this sample can be explained by the abundant microjointing in it (Table 13).

Especially the good abrasion values of porphyritic rapakivi granites (also other porphyritic rapakivi varieties with a coarse-grained groundmass) can be explained by the fact that, as observed in the abrasion test plates (grains 8-12 mm), these test pieces occur to a great extent as monominerals. Therefore they resist grinding abrasion very well.

Even-grained biotite rapakivi

According to the abrasion test, the biotite rapakivi granites studied belong normally to the II strength class (Table 14). Also the three coarse-grained biotite rapakivi samples (variety 5E) are classified as belonging to the I-II strength classes (1991) / II (1993).

Grey Kymi rapakivi

This rapakivi variety consists of hard minerals (quartz, feldspars, topaz). The abrasion test, however, shows the strength class of this rock to be only II (1991) / III (1993), Table 14. Owing to the medium-grained texture and the even grain size of the minerals, the links between the minerals are weak, with the result that the abrasion value cannot be better.

Table 13. Abrasion test and Nordic ball-mill test values and strength classes of porphyritic rapakivi varieties. The strength classes of the abrasion values are based on FinnRA's 1991a and 1993a directions and FinnRA's 1993a and 1993b directions relating to Nordic ball-mill values (see Table 5, on page 44). If the strength class is the same, only one value is given. The textural features of different rapakivi varieties are explained in Table 4 (page 25) and the observation sites in Fig. 1 (page 13).

Rapakivi variety and observation site		Abrasion value/ strength class 1991a; 1993a	Nordic ball-mill value/ strength class 1993a; 1993b
1A	Wiborgite (1)	2.2/II;III	18.3/- ;V
1A	Wiborgite (4)	2.0/II	14.7/IV
1A	Wiborgite (5)	2.2/II;III	18.3/- ;V
1A	Wiborgite (6)	2.2/II;III	15.8/IV
1A	Wiborgite (7)	2.4/III	15.4/IV
1A	Wiborgite (10)	2.3/II;III	16.6/IV
1A	Wiborgite (11)	2.2/II;III	16.2/IV
1A	Wiborgite (12)	2.1/II	16.1/IV
1A	Wiborgite (13)	2.2/II;III	19.3/- ;V
1B	Wiborgite (8)	2.2/II;III	18.8/- ;V
1B	Wiborgite (9)	2.3/II;III	18.0/- ;V
1C	Wiborgite (14)	2.3/II;III	21.5/- ;V
1C	Wiborgite (15)	2.3/II;III	20.7/- ;V
1D	Wiborgite (2)	2.0/II	13.1/III
1D	Wiborgite (3)	2.1/II	13.3/III
1D	Wiborgite (16)	2.3/II;III	12.8/III
2A	Dark-coloured wiborgite (17.1)	2.1/II	17.1/- ;V
2A	Dark-coloured wiborgite (17.2)	2.7/III;IV	17.7/- ;V
2A	Dark-coloured wiborgite (18.1)	2.2/II;III	14.1/IV
2A	Dark-coloured wiborgite (18.2)	2.3/II;III	14.7/IV
2B	Dark-coloured wiborgite (19)	2.3/II;III	18.2/- ;V
2B	Dark-coloured wiborgite (20)	2.2/II;III	18.1/- ;V
3A	Pyterlite (21)	1.8/I ;II	17.9/- ;V
3A	Pyterlite (22)	2.2/II;III	17.9/- ;V
3A	Pyterlite (23)	1.9/II	17.4/- ;V
3A	Pyterlite (24)	2.0/II	20.6/- ;V
3A	Pyterlite (25)	2.1/II	16.8/IV
4A	Porphyritic rapakivi granite (27)	1.8/I ;II	17.3/- ;V
4A	Porphyritic rapakivi granite (28)	2.5/III	23.4/- ;V
4B	Porphyritic rapakivi granite (26.2)	2.2/II;III	14.5/IV
4B	Porphyritic rapakivi granite (29)	2.2/II;III	18.1/- ;V
4C	Porphyritic rapakivi granite (26.1)	1.9/II	9.6/II

Table 14. Abrasion test and Nordic ball-mill test values and strength classes of even-grained biotite rapakivi, grey Kymi rapakivi, porphyry aplite, quartz porphyry, hornblende rapakivi and dark-coloured, even-grained rapakivi (=tirilite). Explanations in Table 13.

Rapakivi variety and observation site		Abrasion value/ strength class 1991a;1993a	Nordic ball-mill value/ strength class 1993a;1993b
5A	Even-grained biotite rapakivi (31.2)	2.0/II	13.7/III
5A	Even-grained biotite rapakivi (38)	2.1/II	11.9/III
5A	Even-grained biotite rapakivi (42)	2.1/II	11.4/III
5A	Even-grained biotite rapakivi (46)	2.3/II;III	14.0/III
5B	Even-grained biotite rapakivi (34.2)	2.2/II;III	20.3/- ;V
5C	Even-grained biotite rapakivi (30)	2.0/II	9.3/II
5C	Even-grained biotite rapakivi (32)	1.7/I ;II	9.7/II
5C	Even-grained biotite rapakivi (33)	1.7/I ;II	8.7/II
5C	Even-grained biotite rapakivi (34.1)	1.7/I ;II	10.7/II
5C	Even-grained biotite rapakivi (40)	1.9/II	9.3/II
5C	Even-grained biotite rapakivi (43)	1.9/II	8.8/II
5D	Even-grained biotite rapakivi (35)	1.9/II	11.4/III
5D	Even-grained biotite rapakivi (44)	2.0/II	12.4/III
5D	Even-grained biotite rapakivi (45)	2.1/II	13.2/III
5E	Even-grained biotite rapakivi (36)	2.0/II	15.5/IV
5E	Even-grained biotite rapakivi (39)	2.1/II	15.7/IV
5E	Even-grained biotite rapakivi (41)	1.7/I ;II	17.2/- ;V
5F	Even-grained biotite rapakivi (31.1)	1.7/I ;II	6.5/I
5F	Even-grained biotite rapakivi (37)	1.8/I ;II	7.6/II
6A	Grey Kymi rapakivi (47)	2.2/II;III	15.6/IV
7A	Porphyry aplite (64)	2.0/II	11.3/III
7A	Porphyry aplite (65)	2.0/II	11.4/III
7A	Porphyry aplite (67)	1.8/I ;II	12.4/III
7B	Porphyry aplite (66)	1.8/I ;II	8.6/II
8A	Quartz porphyry (68)	1.4/I	5.3/I
9A	Hornblende rapakivi (48)	1.9/II	7.2/II
9A	Hornblende rapakivi (49.1)	2.0/II	7.4/II
9A	Hornblende rapakivi (50.1)	1.8/I ;II	6.8/I
9A	Hornblende rapakivi (50.2)	1.8/I ;II	8.4/II
9B	Hornblende rapakivi (49.2)	2.2/II;III	14.7/IV
9C	Hornblende rapakivi (51)	2.0/II	13.1/III
9C	Hornblende rapakivi (52)	1.8/I ;II	12.5/III
9D	Hornblende rapakivi (53)	2.4/III	12.9/III
9D	Hornblende rapakivi (54)	2.7/III;IV	13.6/III
9D	Hornblende rapakivi (57)	2.4/III	13.6/III
9E	Hornblende rapakivi (55)	2.8/III;IV	17.7/- ;V
9F	Hornblende rapakivi (56)	2.5/III	25.5/- ;V
10A	Tirilite (58)	2.3/II;III	12.5/III
10A	Tirilite (59)	2.2/II;III	12.4/III
10A	Tirilite (63.1)	2.2/II;III	13.0/III
10B	Tirilite (60)	3.8/-	20.8/- ;V
10B	Tirilite (61.2)	3.9/-	19.3/- ;V
10C	Tirilite (61.1)	2.7/III;IV	15.3/IV
10C	Tirilite (63.2)	2.9/IV	14.8/IV
10D	Tirilite (62)	2.3/II;III	10.5/II

Porphyry aplit

Owing to the fine-grained groundmass and the "typical" mineral composition of the rapakivi, the porphyry aplites studied belong, in the light of the abrasion test, to the I-II strength class (1991) / II (1993). The samples studied have good abrasion values: 1.8-2.0 (Table 14).

Quartz porphyry

The quartz porphyry sample is, of all the rapakivi samples studied, clearly the best on the basis of its abrasion value (= 1.4). The abrasion value of the I strength class can be explained by the fine-grained groundmass, and the minerals are partly anhedral (Table 14).

Hornblende rapakivi

In the hornblende rapakivi granites of the Lappeenranta area (Table 14, varieties 9D-9F), fine-grained quartz does not occur, and the hornblende is partly also coarse-grained. Some of the rock fragments (8-12 mm) in the abrasion test plates can be observed to be composed solely of monomineralic hornblende, which weakens the received abrasion strength class: III (1991) / III-IV (1993).

The hornblende rapakivi contained in the Jaala-Iitti complex (variety 9A) differs most markedly from that in the Lappeenranta area with respect to its grain size distribution: the groundmass is fine-grained. Although the hornblende content in the rocks of both areas is the same, the fine-grained groundmass of the Jaala-Iitti hornblende rapakivi results in a better abrasion strength class of I-II (1991) / II (1993).

According to the abrasion test, the hornblende rapakivi granites of the Pyhtää and Hamina areas belong to the I-II (1991) / II (1993) strength classes (Table 14, variety 9C). The fine-grained quartz occurring in the groundmass improves the abrasion resistance of these rocks.

Dark-coloured, even-grained rapakivi (tirilite)

The variation in the abundance of microjointing occurring in the samples studied appears also in the strength classes obtained through the abrasion test (Table 14) - to wit, the variation is large: II-classless (1991) / III-classless (1993):

- The rocks to the south of Lappeenranta and in the Ylämaa area with very abundant microjointing are classless (variety 10B, Table 4).
- In the Ylämaa area, the rocks containing abundant microjointing fall into the strength class III-IV (1991) / IV (1993), (variety 10C).
- The rocks to the west of Lappeenranta and in the Ylämaa area with slight microjointing are in the strength class II (1991) / III (1993), (variety 10A).
- The rock occurring in the Ylämaa area (variety 10D), which deviates from the other samples by its smaller grain size and lack of microjointing, also belongs to strength class II (1991) / III (1993).

5.2.6 Nordic ball-mill value

In FinnRA's work instructions for the years 1993-94 (Tables 5A and 5B, on page 44), the strength class of the asphalt pavement rock material is determined also by the Nordic ball-mill test. The strength class limits of the Nordic ball-mill test set by these instructions are otherwise the same, but to the instructions of 1994 (FinnRA 1993b) is added strength class V (II). In the present study, this change has been taken into account in that if the rock material belongs to strength class V (II), it has been mentioned in the results.

Wiborgite

Typically, according to the Nordic ball-mill test, the wiborgites belong to the IV strength class (Table 13). The coarse-grained wiborgites in the groundmass and the wiborgites having abundant microjointing, however, are classless (1993) / V strength class (1994), (Table 4 on page 25, varieties 1C and 1B).

Common features of the wiborgite samples belonging to the III strength class (variety 1D) are the fine- to medium-grained groundmass, the small amount of microjointing and the rich content of fine-grained quartz, both in the groundmass and as inclusions in the ovoids.

Dark-coloured wiborgite

The dark-coloured wiborgite samples are classified, according to the Nordic ball-mill test, as IV-classless (1993) / IV-V (1994), Table 13. The samples from the second observation site at Kuusankoski (No. 17) are classless (1993) / V strength class (1994). Accordingly, they do not differ from the samples from the Kaipiainen and Lappeenranta areas (variety 2B), where abundant microjointing occurs.

Pyterlite

Typically, according to the Nordic ball-mill test, the pyterlites are classified as classless (1993) / V strength class (1994), Table 13. The weak strength values are due to the rock features: coarse-grained texture, euhedral minerals, lack of fine-grained minerals, low content of mafic minerals and occurrence of marked microjointing.

Porphyritic rapakivi granite

Among the porphyritic rapakivi varieties, the strength classes obtained by the Nordic ball-mill test of the porphyritic rapakivi granites vary most of all: II-classless (1993) / II-V (1994), Table 13. The mineral composition and texture of the porphyritic rapakivi granites closely resemble those of the pyterlites, so that they are usually classified as classless (1993) / V class (1994).

The porphyritic rapakivi granite associated with the Jaala-Iitti hornblende rapakivi complex (observation site 26.1) contains an abundance of fine-grained quartz, with no microjointing observable, thus representing a deviation from the other samples. This sample belongs to the II strength class.

Even-grained biotite rapakivi

The even-grained biotite rapakivi varieties belong, as indicated by the Nordic ball-mill test, to the strength classes I-classless (1993) / I-V (1994), Table 14. In the light of the Nordic ball-mill test, the following conclusions can be made:

- The coarse-grained and typical medium-grained biotite rapakivi varieties with abundant microjointing belong to the IV-classless (1993) / IV-V (1994) strength classes (varieties 5E and 5B).
- The typical medium-grained biotite rapakivi variety belongs to the III strength class (variety 5A).
- The typical medium-grained biotite rapakivi variety with abundant fine-grained quartz, as well as considerable microjointing, also belongs to the III strength class (variety 5D).
- The typical medium-grained biotite rapakivi variety with an abundance of fine-grained quartz belongs to the II strength class (variety 5C).
- The fine-grained biotite rapakivi variety with an abundance of fine-grained quartz is in strength classes I-II (variety 5F).

Grey Kymi rapakivi

The grey Kymi rapakivi belongs, as indicated by the Nordic ball-mill test, to the IV strength class (Table 14). With regard to its textural features, this rock is similar to the typical medium-grained biotite rapakivi, which, however, represents a better strength class, III.

The weak Nordic ball-mill value of the grey Kymi rapakivi is due to the clearly observed jointing in the bedrock, which can be seen also in the rock as abundant microjointing in places. Nordic ball-mill values of class V have also been reached in the research.

Porphyry aplite

Although the groundmass is fine-grained, according to the Nordic ball-mill test, the porphyry aplites are III-class rock material. Only the sample from observation site No. 66 is better than the other samples: class II (Table 14). The superior wearing resistance of this sample can be explained by its exceptionally high quartz content, as noticed before.

Quartz porphyry

Also on the basis of the Nordic ball-mill test, the quartz porphyry sample belongs to the I strength class (Table 14). The I strength class can be explained by the fine-grained texture and abundance of quartz.

Hornblende rapakivi

The hornblende rapakivi varieties are classified, in the light of the Nordic ball-mill test, as I-classless (1993) / I-V (1994), Table 14. On the basis of the Nordic ball-mill test, the following conclusions may be drawn:

- The rocks of the Jaala-Iitti complex belong mostly to the II strength class, but partly also to class I (variety 9A). Here and there, abundant microjointing occurs in the rock, which results in strength class IV (variety 9B).

- The strength class of the rocks from the Lappeenranta area is III (variety 9D) and the strength class of the coarse-grained variety or the ones marked by abundant microjointing is, however, classless (1993) / V (1994), (varieties 9E and 9F).
- The rocks of Pyhtää and Hamina fall into strength class III (variety 9C).

Dark-coloured, even-grained rapakivi (tirilite)

The dark-coloured, even-grained rapakivi varieties of the Lappeenranta and Ylämaa areas belong, as indicated by the Nordic ball-mill test, to strength classes II-classless (1993) / II-V (1994), Table 14. The differences between the classes are mostly due to the amount of microjointing, as has also been brought out by the Los Angeles and abrasion tests. The following conclusions are based on the Nordic ball-mill test:

- The rocks south of Lappeenranta and in the Ylämaa area, which exhibit very abundant microjointing, is designated as classless (1993) / V strength class (1994),(variety 10B).
- The rocks with abundant microjointing from the Ylämaa area are in the IV strength class (variety 10C).
- To the west of Lappeenranta and in the Ylämaa area, the rocks are only slightly microjointed, their strength class being III (variety 10A).
- The rock in the Ylämaa area, differing from the others (with abundant fine-grained quartz, slight microjointing and a fine-grained groundmass), belongs to the best strength class II (variety 10D).

5.2.7 Point-load strength index

In accordance with FinnRA's work instructions for 1991-94, the point-load test was one of the methods used in studying the asphalt pavement rock materials. As stated in the 1991 work instructions, the point-load test can be done on both core samples and rock aggregates. On the basis of the 1993 (Tielaitos 1993a) and 1994 (Tielaitos 1993b) instructions, the point-load tests are performed only with core samples (Ø 32-62 mm). Because it was discovered that the results arrived at by tests with rock aggregates differed from those yielded by core samples, and very considerable variation of parallel tests characterized the results using rock aggregates (Lappalainen 1993).

The point-load tests performed during the present study involved the following:
- Ø 32-mm core material, from which 16 parallel samples were studied.
- Rock aggregate (Ø 10-22 mm), from which 20 parallel samples were studied.
- Ø 26-mm core material (minidrill), from which 10 parallel samples were studied.

The results are shown as the mean value of the parallel tests after eliminating the two highest and two lowest values.

The standard deviation of the results of the parallel point-load tests done on the Ø 32-mm core samples and rock aggregates is small; the mean value of the standard deviation in both tests is 1.3; and the tests done on the Ø 26-mm core sample show even lower values , 0.7 (Table 15). There are no differences between the several rapakivi varieties, and the standard deviation of all of them is about the same.

Table 16 presents the correlation between the results of different point-load tests. It can also be seen in Table 16 and in Figure 18 that the correlation between the results of the core samples and the rock aggregates is highly significant.

In this research, the point-load strength indices and classes have been studied on the basis of the point-load test results of Ø 32 mm, rock aggregate and Ø 26 mm samples (Tables 17 and 18). A closer strength classification of the rapakivi varieties has been made on the basis of the point-load test results of Ø 32 mm samples.

The limits of the strength classes for the point-load test set by the 1994 crushing instructions and the 1993 work instructions have become less demanding than those of the 1991 work instructions (Tables 5A, 5B and 5C, on page 44). Further, strength class V has been added to the work instructions of 1994. In the study, the strength class of the samples has been presented according to these Tables.

Wiborgite

The wiborgite samples studied belong, according to the point-load test, to the strength classes III-classless (1991) / III-V (1994), while "typical wiborgite" falls into the IV class (Table 17). The classless (1991) / class V (1994) wiborgites are either coarse-grained or they contain abundant microjointing (varieties 1C and 1B, Table 4 on page 25). Common to class III wiborgite is a fine- to medium-grained groundmass, a small amount of microjointing and abundant occurrence of fine-grained quartz.

Dark-coloured wiborgite

The dark-coloured wiborgites belong, according to the point- load test, to the III-classless (1991) / II-V (1994) strength classes (Table 17). The samples from Kaipiainen and Lappeenranta (variety 2B), with abundant microjointing, fall into the classless (1991) / classes IV-V (1994) categories.

The samples from the Kuusankoski area are in the III-IV (1991) / II-III (1994) strength classes (variety 2A). The markedly superior strength qualities of the Kuusankoski area samples can be explained by their smaller grain size and clearly slighter microjointing. The lower strength values of the parallel samples from the Kuusankoski area (17.2 and 18.2) are due to their marked microjointing.

Pyterlite

According to the point-load test, the five pyterlite samples studied are to be classified as IV-classless (1991) / IV-V (1994), (Table 17). The poor results are mainly due to the textural features of the rocks (coarse-grained, euhedral minerals) and their abundant microjointing.

Porphyritic rapakivi granite

The porphyritic rapakivi granites belong, according to the point-load test, to the strength classes III-classless (1991) / II-V (1994), while this rapakivi variety typically belongs to the IV class (Table 17). The rocks from observation sites 26.2-29 are quite similar in composition and texture. The differences in strength classes are due to the amount of microjointing.

The sample from observation site No. 26.1 is in the III (1991) / II (1994) strength class. Its superior strength value is due to the textural features (abundant fine-grained quartz in the groundmass) and the lack of microjointing.

Even-grained biotite rapakivi

According to the point-load test, the even-grained biotite rapakivi samples belong to the I-classless (1991) / I-IV (1994) strength classes (Table 18). The variation in strength classes results from textural features and the amount of microjointing:

- The coarse-grained and the typical medium-grained biotite rapakivi varieties with abundant microjointing belong to the IV-classless (1991) / III-IV (1994) strength classes (varieties 5E and 5B).
- The typical medium-grained biotite rapakivi variety belongs to the III (1991) / II-III (1994) strength classes (variety 5A).
- The typical medium-grained biotite rapakivi variety with an abundance of fine-grained quartz, but also much microjointing, also belongs to the III (1991) / II-III (1994) strength classes (variety 5D).
- The typical medium-grained biotite rapakivi variety with abundant fine-grained quartz belongs to the I-III (1991) / I-II (1994) strength classes (variety 5C).
- The fine-grained biotite rapakivi variety with abundant fine-grained quartz belongs to the I-II strength classes (variety 5F).

Grey Kymi rapakivi

This rapakivi variety belongs, according to the point-load test, to the IV strength class (Table 18). The low strength value results from the textural features (granular texture) and abundant microjointing.

Porphyry aplite

The porphyry aplites are, according to the point-load test, in the I-III (1991) / I-II (1994) strength classes, (Table 18). The good strength value of the porphyry aplite is due to the fine-grained groundmass and the lack of microjointing.

Quartz porphyry

According to the point-load test, the quartz porphyry belongs to the I strength class (Table 18). The good strength value is due to the fine grain size and andhedral minerals in the groundmass.

Table 15. Standard deviations of point-load parallel test indices.

Rapakivi varieties	Standard deviation: mean value / range of variation		
	Core sample Ø 32 mm	Rock aggregate	Core sample Ø 26 mm
All rapakivi varieties	1.3/0.6-2.4	1.3/0.5-2.3	0.7/0.2-1.7
Porphyritic varieties	1.3/0.7-2.4	1.3/0.5-2.3	0.8/0.4-1.7
Even-grained varieties	1.3/0.6-2.4	1.4/1.0-2.1	0.7/0.2-1.4
Dark-coloured varieties	1.3/0.6-1.8	1.3/0.6-2.2	0.7/0.4-1.3

Porphyritic varieties: wiborgite, dark-coloured wiborgite, pyterlite, porphyritic rapakivi granite

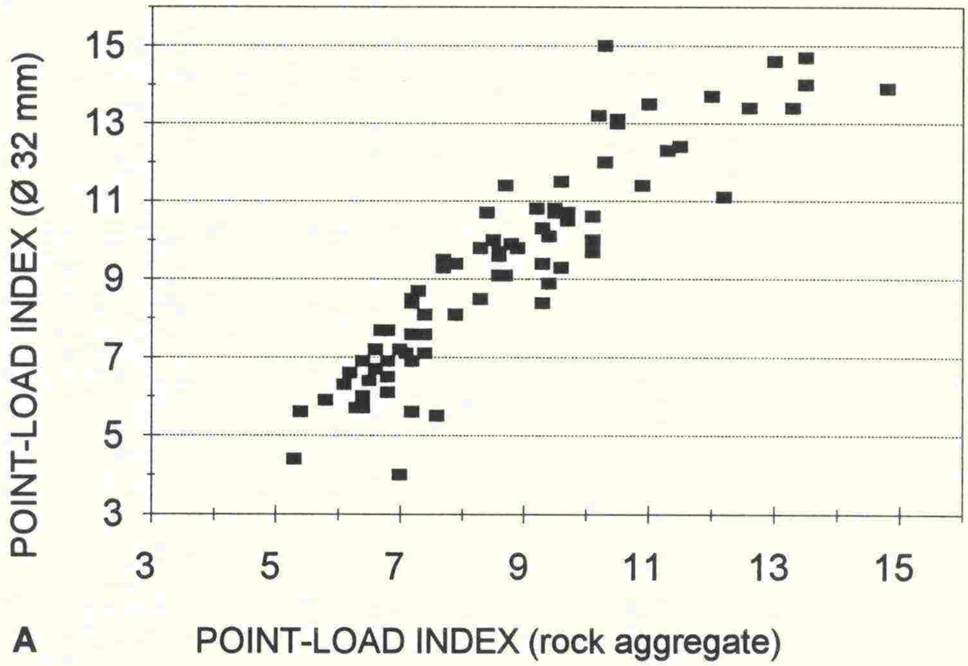
Even-grained varieties: even-grained biotite rapakivi, grey Kymi rapakivi, porphyry aplite, quartz prophyry

Dark-coloured varieties: hornblende rapakivi, dark-coloured, even-grained rapakivi (tirilite)

Table 16. Correlations of point-load strength indices between parallel point-load tests.

Rapakivi varieties	Core samples Ø 32 mm & Ø 26 mm	Core sample Ø 32 mm & rock aggregate	Core sample Ø 26 mm & rock aggregate
All rapakivi varieties	0.90***	0.91***	0.86***
Porphyritic varieties	0.87***	0.85***	0.85***
Even-grained varieties	0.85***	0.88***	0.85***
Dark-coloured varieties	0.89***	0.94***	0.82***

*** = highly significant correlation (risk level 0.1 %)
** = significant correlation (risk level 1.0 %)
* = almost significant correlation (risk level 5.0 %)



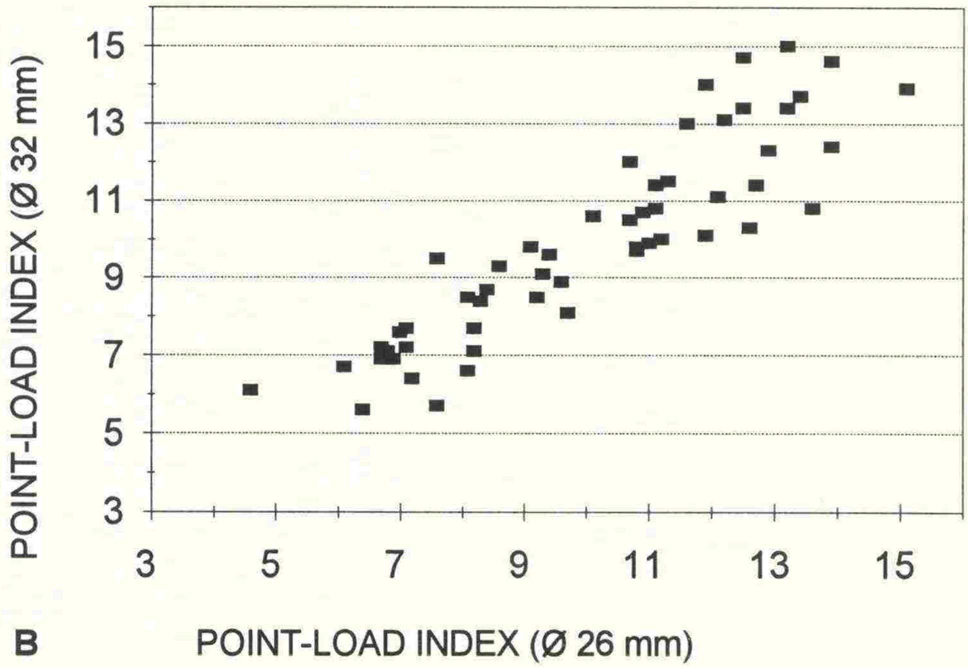


*Fig. 18. Correlation between the Ø 32 mm core samples and the rock aggregates, r = 0.91*** (A), and the Ø 32 mm & Ø 26 mm core samples, r = 0.90*** (B).*

Table 17. Point-load test values and strength classes of porphyritic rapakivi varieties. Strength classes of point-load indices are based on FinnRA's 1991a, 1993a and 1993b directions (see Table 5, page 44). If the strength class is the same, only one value is marked. The point-load test is performed with a point-load apparatus (1= core sample Ø 32 mm; 2= rock aggregate; 3= core sample Ø 26 mm). The textural features of different rapakivi varieties are explained in Table 4 (page 25) and the observation sites in Fig. 1 (page 13).

Rapakivi variety and observation site	Point-load strength indixes / strength classes 1991a; 1993a; 1993b					
	1		2		3	
1A Wiborgite (1)	6.1	- IV IV	6.8	- IV IV	4.6	- - V
1A Wiborgite (4)	7.2	IV	7.0	IV	6.7	- IV IV
1A Wiborgite (5)	6.0	- IV IV	6.4	- IV IV	-	
1A Wiborgite (6)	6.5	- IV IV	6.8	- IV IV	-	
1A Wiborgite (7)	7.6	IV	7.4	IV	7.0	IV
1A Wiborgite (10)	6.9	- IV IV	6.8	- IV IV	-	
1A Wiborgite (11)	8.4	IV III III	9.3	III	-	
1A Wiborgite (12)	9.8	III	8.3	IV III III	9.1	III
1A Wiborgite (13)	6.9	- IV IV	7.2	IV	6.7	- IV IV
1B Wiborgite (8)	5.7	- - V	6.3	- IV IV	-	
1B Wiborgite (9)	5.6	- - V	7.2	IV	6.4	- IV IV
1C Wiborgite (14)	5.7	- - V	6.4	- IV IV	7.6	IV
1C Wiborgite (15)	4.4	- - V	5.3	- - V	-	
1D Wiborgite (2)	9.3	III	9.6	III	8.6	IV III III
1D Wiborgite (3)	9.6	III	8.6	IV III III	9.4	III
1D Wiborgite (16)	9.7	III	10.1	III II II	10.8	III II II
2A Dark-coloured wiborgite (17.1)	10.0	III II II	10.1	III II II	11.2	II
2A Dark-coloured wiborgite (17.2)	8.1	IV III III	7.9	IV	9.7	III
2A Dark-coloured wiborgite (18.1)	10.5	III II II	9.7	III	10.7	III II II
2A Dark-coloured wiborgite (18.2)	8.9	IV III III	9.4	III	9.6	III
2B Dark-coloured wiborgite (19)	6.9	- IV IV	6.4	- IV IV	6.9	- IV IV
2B Dark-coloured wiborgite (20)	4.0	- - V	7.0	IV	-	
3A Pyterlite (21)	6.4	- IV IV	6.5	- IV IV	7.2	IV
3A Pyterlite (22)	7.1	IV	7.1	IV	6.8	- IV IV
3A Pyterlite (23)	7.1	IV	7.4	IV	8.2	IV III III
3A Pyterlite (24)	5.5	- - V	7.6	IV -		
3A Pyterlite (25)	6.3	- IV IV	6.1	- IV IV	-	
4A Porphyritic rapakivi granite (27)	5.9	- - V	5.8	- - V	-	
4A Porphyritic rapakivi granite (28)	7.2	IV	6.6	- IV IV	7.1	IV
4B Porphyritic rapakivi granite (26.2)	8.1	IV III III	7.4	IV	-	
4B Porphyritic rapakivi granite (29)	8.4	IV III III	7.2	IV	8.3	IV III III
4C Porphyritic rapakivi granite (26.1)	10.1	III II II	9.4	III	11.9	II

Table 18. Point-load test values and strength classes of even-grained biotite rapakivi, grey Kymi rapakivi, porphyry aplite, quartz porphyry, hornblende rapakivi and dark-coloured, even-grained rapakivi (=tirilite). Explanations in Table 17.

Rapakivi variety and observation site		Point load strength indixes / strength classes 1991a; 1993a; 1993b					
		1		2		3	
5A Even-grained biotite rapakivi	(31.2)	10.8	III II II	9.2	III	13.6	I
5A Even-grained biotite rapakivi	(38)	10.6	III II II	10.1	III II II	10.1	III II II
5A Even-grained biotite rapakivi	(42)	10.7	III II II	8.4	IV III III	-	
5A Even-grained biotite rapakivi	(46)	9.9	III	8.8	IV III III	11.0	II
5B Even-grained biotite rapakivi	(34.2)	6.6	- IV IV	6.2	- IV IV	8.1	IV III III
5C Even-grained biotite rapakivi	(30)	12.0	II	10.3	III II II	10.7	III II II
5C Even-grained biotite rapakivi	(32)	15.0	I	10.3	III II II	13.2	I
5C Even-grained biotite rapakivi	(33)	14.6	I	13.0	I	13.9	I
5C Even-grained biotite rapakivi	(34.1)	12.3	II	11.3	II	12.9	II
5C Even-grained biotite rapakivi	(40)	13.2	I	10.2	III II II	-	
5C Even-grained biotite rapakivi	(43)	10.3	III II II	9.3	III	12.6	II
5D Even-grained biotite rapakivi	(35)	10.8	III II II	9.5	III	11.1	II
5D Even-grained biotite rapakivi	(44)	10.7	III II II	9.7	III	10.9	III II II
5D Even-grained biotite rapakivi	(45)	9.1	III	8.6	IV III III	-	
5E Even-grained biotite rapakivi	(36)	8.5	IV III III	7.2	IV	9.2	III
5E Even-grainde biotite rapakivi	(39)	7.6	IV	7.2	IV -		
5E Even-grained biotite rapakivi	(41)	7.7	IV	6.8	- IV IV	7.1	IV
5F Even-grained biotite rapakivi	(31.1)	13.4	I	12.6	II	12.5	II
5F Even-grained biotite rapakivi	(37)	12.4	II	11.5	II	13.9	I
6A Grey Kymi rapakivi	(47)	7.7	IV	6.7	- IV IV	8.2	IV III III
7A Porphyry aplite	(64)	13.0	I	10.5	III II II	11.6	II
7A Porphyry aplite	(65)	10.7	III II II	9.5	III -		
7A Porphyry aplite	(67)	11.5	II	9.6	III	11.3	II
7B Porphyry aplite	(66)	11.4	II	10.9	III II II	11.1	II
8A Quartz porphyry	(68)	13.9	I	14.8	I	15.1	I
9A Hornblende rapakivi	(48)	13.4	I	13.3	I	13.2	I
9A Hornblende rapakivi	(49.1)	13.7	I	12.0	II	13.4	I
9A Hornblende rapakivi	(50.1)	14.7	I	13.5	I	12.5	II
9A Hornblende rapakivi	(50.2)	14.0	I	13.5	I	11.9	II
9B Hornblende rapakivi	(49.2)	8.7	IV III III	7.3	IV	8.4	IV III III
9C Hornblende rapakivi	(51)	8.5	IV III III	8.3	IV III III	8.1	IV III III
9C Hornblende rapakivi	(52)	11.1	II	12.2	II	12.1	II
9D Hornblende rapakivi	(53)	9.4	III	9.3	III	-	
9D Hornblende rapakivi	(54)	9.7	III	8.6	IV III III	-	
9D Hornblende rapakivi	(57)	9.1	III	8.7	IV III III	9.3	III
9E Hornblende rapakivi	(55)	9.8	III	8.9	IV III III	10.8	III II II
9F Hornblende rapakivi	(56)	6.7	- IV IV	6.6	- IV IV	6.1	- IV IV
10A Tirilite	(58)	10.0	III II II	8.5	IV III III	-	
10A Tirilite	(59)	9.4	III	7.9	IV	-	
10A Tirilite	(63.1)	13.1	I	10.5	III II II	12.2	II
10B Tirilite	(60)	5.6	- - V	5.4	- - V	-	
10B Tirilite	(61.2)	9.5	III	7.7	IV	7.6	IV
10C Tirilite	(61.1)	11.4	II	8.7	IV III III	12.7	II
10C Tirilite	(63.2)	9.3	III	7.7	IV	-	
10D Tirilite	(62)	13.5	I	11.0	II	-	

Hornblende rapakivi

The hornblende rapakivi granites belong, according to the point-load test, to the I-classless (1991) / I-IV (1994) strength classes (Table 18). The variation of strength classes results from textural features and the amount of microjointing:

- The rocks in the Jaala-Iitti complex belong into the I strength class (variety 9A). The good strength values can be explained by the fine- to medium-grained groundmass and the abundance of hornblende. The poorer strength class of variety 9B is due to its abundant microjointing.
- The rocks from the Lappeenranta area belong to strength class III (varieties 9D and 9E). The lower strength values than in the Jaala-Iitti area are due to the bigger grain size of the groundmass and the lack of fine-grained material. The poor strength class, classless (1991) / IV (1994), of variety 9F is due to its abundant microjointing.
- The rock from the Pyhtää area belongs to the IV (1991) / III (1994) strength class and the one from the Hamina area to class II (variety 9C, observation sites 51 and 52). Their textural features are similar to those of the samples from the Lappeenranta area.

Dark-coloured, even-grained rapakivi (tirilite)

The strength class of the rocks from the Lappeenranta and Ylämaa areas varies between I and classless (1991) / I and V (1994), according to the point-load test (Table 18). The differences result mostly from the amount of microjointing:

- The rocks to the south of Lappeenranta and in the Ylämaa area with very abundant microjointing are III-classless (1991) / III-V (1994) strength classes (variety 10B).
- In the Ylämaa area, the rocks containing abundant microjointing belong to the II-III strength classes (variety 10C).
- The rocks to the west of Lappeenranta with slight microjointing are in the III (1991) / II-III (1994) strength classes (observation sites 58 and 59) and the corresponding rock in the Ylämaa area in strength class I (observation site No. 63.1), (variety 10A).
- Deviating from the other samples, the rock in the Ylämaa area (e.g., smaller grain size and lack of microjointing) belongs to the I strength class (variety 10D).

5.3 Correlations between the strength tests done and comparison with the results of the Kouvola and Kerava rock aggregate test roads

For comparison of different test results, Pearson correlations have been calculated. Table 19 shows the correlations between the various strength tests performed on different rapakivi samples. The table shows that the correlations between the different tests done on all the samples are highly significant. Only the correlation between the abrasion and point-load tests (Ø 26 mm core sample) is significant.

The best correlations are between the different point-load tests, the standard deviation of which was also found to be very low (see Tables 15-16 and Figure 18 on pages 66-67). Also the values of the correlation coefficient between the strength tests (Nordic ball-mill, point-load and Los Angeles test), worked out according to FinnRA's crushing instructions (Tielaitos 1993b), are very high (Figures 19 and 20 A).

Table 19. Correlations between different laboratory test values of rapakivi samples. Rapakivi varieties are explained in Table 15 on page 66.

	1	2	3	4	5	6	7
1. Los Angeles value:							
a) All samples	**1**	**0.88*** **	**0.63*** **	**0.92*** **	**0.89*** **	**0.88*** **	**0.83*** **
b) Porphyritic	1	0.88***	0.07	0.75***	0.80***	0.70***	0.66**
c) Even-grained	1	0.92***	0.60**	0.94***	0.88***	0.92***	0.83***
d) Dark-coloured	1	0.87***	0.94***	0.95***	0.90***	0.88***	0.79**
2. Swedish impact value:							
a) All samples		**1**	**0.38*** **	**0.78*** **	**0.82*** **	**0.81*** **	**0.76*** **
b) Porphyritic		1	0.04	0.68***	0.67***	0.63***	0.50*
c) Even-grained		1	0.62***	0.88***	0.81***	0.80***	0.77***
d) Dark-coloured		1	0.72***	0.81***	0.86***	0.85***	0.85***
3. Abrasion value:							
a) All samples			**1**	**0.70*** **	**0.42*** **	**0.48*** **	**0.43** **
b) Porphyritic			1	0.25	0.04	0.04	0.10
c) Even-grained			1	0.64***	0.65***	0.72***	0.57**
d) Dark-coloured			1	0.89***	0.74***	0.74***	0.49
4. Nordic ball-mill value:							
a) All samples				**1**	**0.83*** **	**0.83*** **	**0.81*** **
b) Porphyritic				1	0.66***	0.69***	0.63**
c) Even-grained				1	0.86***	0.90***	0.81***
d) Dark-coloured				1	0.88***	0.84***	0.78**
5. Point-load strength index (core Ø 32 mm):							
a) All samples					**1**	**0.91*** **	**0.90*** **
b) Porphyritic					1	0.85***	0.87***
c) Even-grained					1	0.88***	0.85***
d) Dark-coloured					1	0.94***	0.89***
6. Point-load strength index (rock aggregate):							
a) All samples						**1**	**0.86*** **
b) Porphyritic						1	0.85***
c) Even-grained						1	0.85***
d) Dark-coloured						1	0.82***
7. Point-load strength index (core Ø 26 mm):							
a) All samples							**1**
b) Porphyritic							1
c) Even-grained							1
d) Dark-coloured							1

*** = highly significant correlation (risk level 0.1 %)
** = significant correlation (risk level 1.0 %)
* = almost significant correlation (risk level 5.0 %)

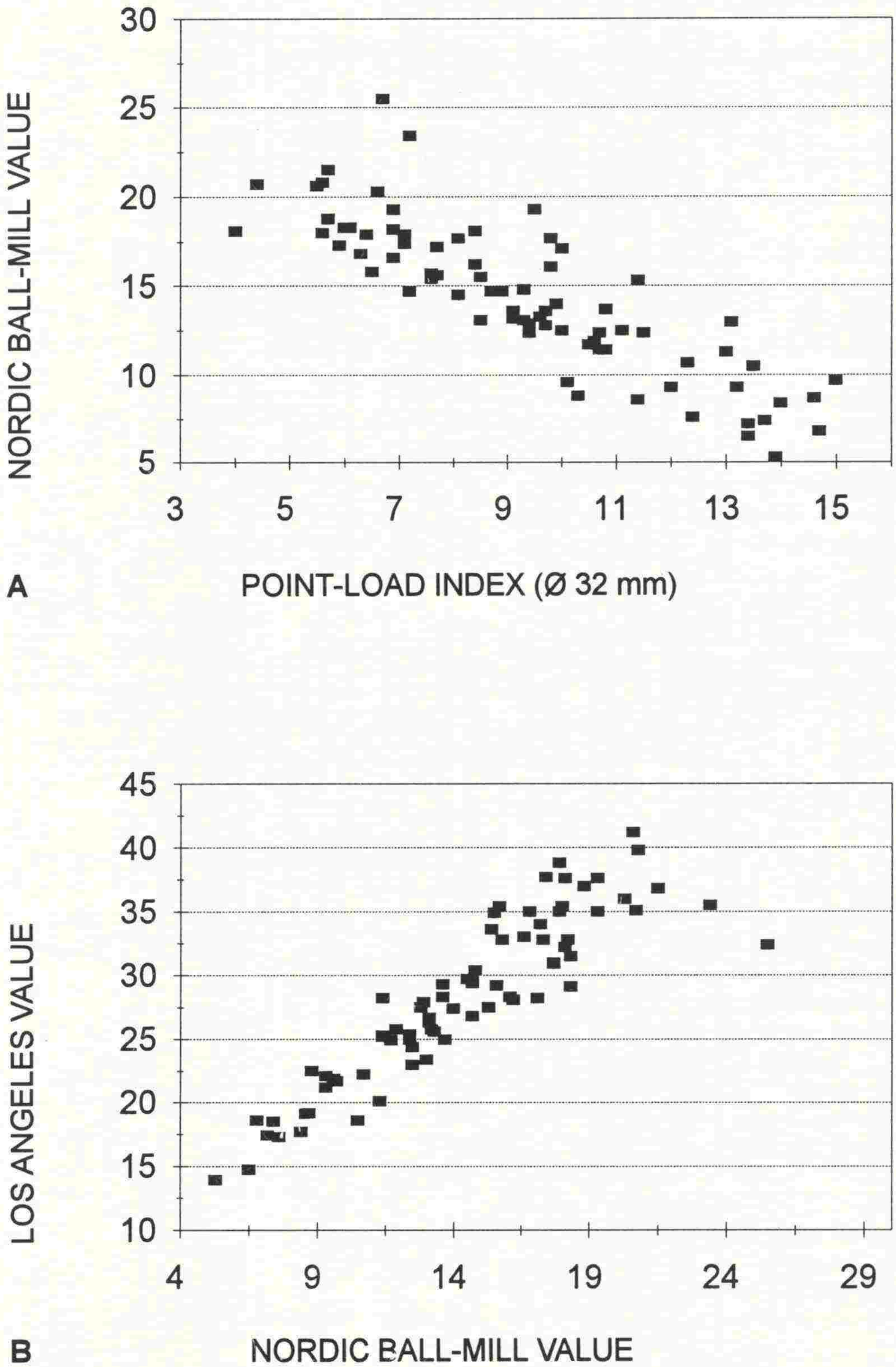
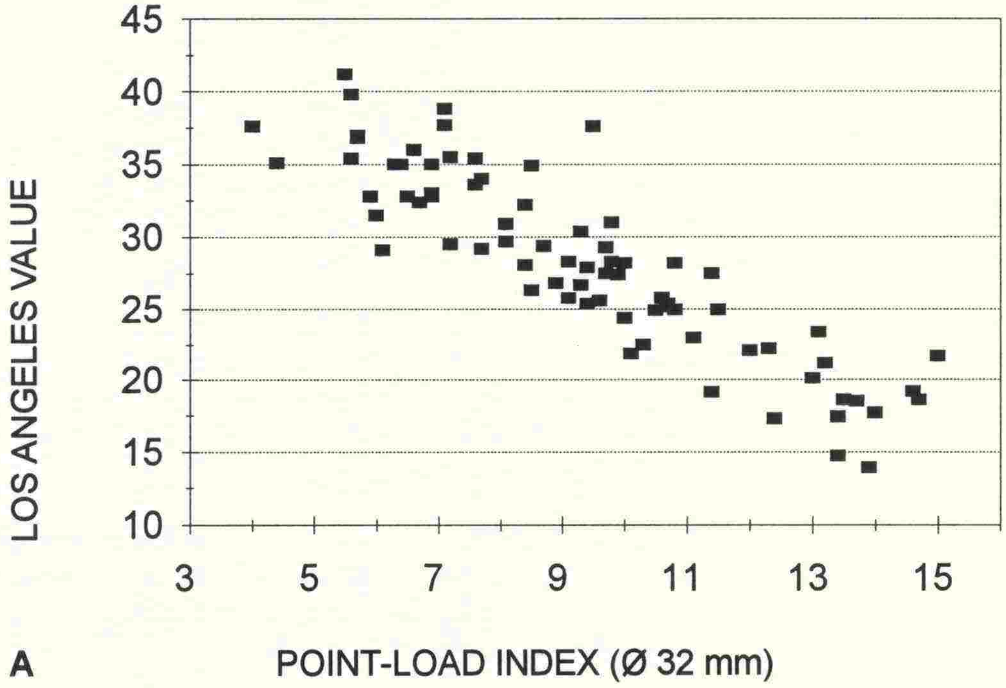


*Fig. 19. Correlations between Nordic ball-mill and point-load tests, r = 0.83*** (A) and Nordic ball-mill and Los Angeles tests, r = 0.92*** (B) performed on rapakivi granite samples.*



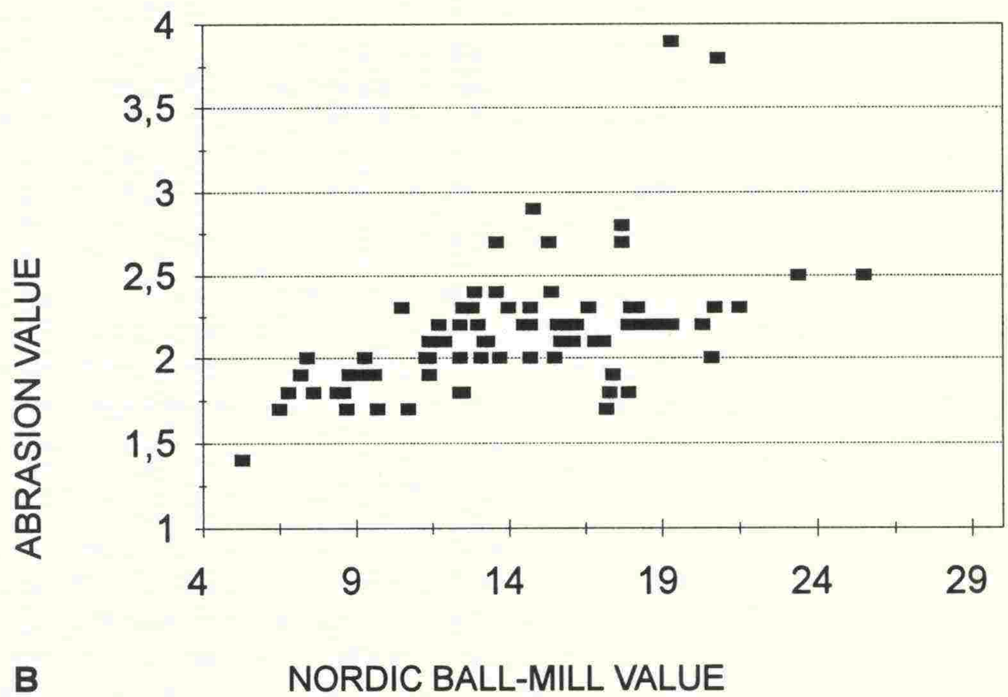


*Fig. 20. Correlations between point-load and Los Angeles tests, r = 0.89*** (A) and Nordic ball-mill and abrasion tests, r = 0.70*** (B) performed on rapakivi granite samples.*

In FinnRA's work instructions for the years 1988-93, the abrasion test was one of the test methods; and, in the 1994 work instructions (Tielaitos 1993b), the abrasion test is replaced by the Nordic ball-mill test. According to the present study, the correlations between these tests are highly significant (Table 19 and Figure 20 B). Only the correlation with the porphyritic variety is not significant (r=0.25), because this variety resists abrasing wear (abrasion test) clearly better than striking strain (Nordic ball-mill test).

Lappalainen (1987) explained in his study the correlations between different test methods. The research material contained 10 crushed rock samples and one crushed gravel sample (two granites, granodiorite, tonalite, quartz diorite, gabbro, quartzite, amfibolite, mica gneiss, tuffite and crushed gravel). The methods used included the Los Angeles, Swedish impact, abrasion and point-load tests (Ø 32 core sample).

According to the Lappalainen's study, the correlation between the Los Angeles and Swedish impact tests is highly significant (r = 0.98***) and that between the abrasion and point-load tests almost significant (r= 0.62*). The correlations between other tests were very low. The difference between the results of Lappalainen's work and the present study can be explained by the small number of his samples and the larger variation of the rock types.

This study also examines the repetition of the Nordic ball-mill test with two parallel samples. The Nordic ball-mill tests were made with "normal rock aggregate" and in addition with crushed core samples (Ø 32 mm). The research material contained 10 rock samples from which five were rapakivi granites used in this study (Appendix 2).

According to the results, the correlations between the parallel samples are highly significant (rock aggregate, r= 0.99***; core sample, r= 0.99***). And also the correlation between the rock aggregate and the crushed core sample is highly significant, r= 0.98*** (Fig. 21).

Tables 20 and 21 show the correlations between the strength tests done on the rock materials used on the Kouvola and Kerava rock aggregate test roads. The reliability of the statistical methods is reduced by the small number of samples (Kouvola n = 13, Kerava n = 15,). The results of the strength tests are presented along with the strength classes in Appendices 3 and 4. Judged by the mix samples from the rock aggregate used on the Kouvola rock aggregate test road, the binder contents and rock aggregate mixtures (grain size distribution) correspond with the work instructions.

There are similarities in the correlations between the strength tests done on the rock materials of the Kouvola and Kerava rock aggregate test roads. On the basis of the results in both cases, the correlation between the Los Angeles and Swedish impact tests is highly significant (r= 0.95*** and r= 0.88***). Moreover, a clear correlation exists between the Nordic ball-mill and abrasion tests (r= 0.63* and r= 0.72*) and the Nordic ball-mill and point-load tests (r= 0.87*** and r= 0.63*), (Tables 20 and 21).

On the basis of the test results obtained from the Kouvola rock aggregate test road, the correlation between the point-load tests (tests 5 and 6) is highly significant (r= 0.82***). In the Kouvola results, the correlations between the rapakivi granites and the non-rapakivi granites are also calculated separately. Particularly the Los Angeles and Nordic ball-mill tests correlate better with rapakivi granites than with non-rapakivi granites. The reason is that the rocks which contain Fe-Mg -minerals (especially biotite) abundantly (over 15 %) are markedly less resistant to scratching and wearing (Nordic ball-mill test) than impacting and wearing (Los Angeles test).

Tables 22 and 23 show the correlations between both the amount of wear and the rut depth arrived at in different tests of the rock materials used in the Kouvola and Kerava test roads. On the basis of the results from both test roads, the Nordic ball-mill (r= 0.90*** and r= 0.89***) and point-load (core Ø 32 mm) tests (r= 0.92*** and r= 0.82***) correlate highly significantly with the amount of wear. On the basis of the Kerava results, also the abrasion (r= 0.80***) and SRK (pavement core sample) tests (r = 0.85***) correlate highly significantly with the amount of wear and, on the basis of the Kouvola results, the point-load test carried out with rock aggregates (r= 0.80***).

When the results from the Kouvola test road are examined (Table 22), it can be seen that as regards the rapakivi granites, the Los Angeles test correlates significantly with the amount of wear (r= 0.91**). On the other hand, as regards the non-rapakivi granites, the correlation between the Los Angeles test and the amount of wear is low (r= 0.35).

The correlation between the amount of wear and the rut depth on the Kerava rock aggregate test road is quite low (r= 0.56*). This has been explained to result from, among other things, deformation of the pavement and the geometry of the road (Alkio & Vuorinen 1992). So also the correlations between the tests and the rut depth are clearly lower than the correlation between the tests and the amount of wear. The SRK (rock sample) test correlates best with the rut depth (r= 0.66**), the point-load test (r= 0.57*) and the Nordic ball-mill test (r= 0.62), Table 23.

The correlation between the amount of wear and the rut depth on the Kouvola rock aggregate test road is highly significant (0.92***; 1990-94). Thus the same tests that correlate with the amount of wear also correlate with the rut depth (Table 22). Figures 22 and 23 show the correlations between the Nordic ball-mill, point-load, Los Angeles and abrasion tests and ruth depths. The correlation between the Los Angeles test and rut depth is weakened by two samples (Fig. 23 top left; biotite gneiss and plagioclase porphyrite), which differ from other samples. In Appendix 5 are shown the correlations between these tests and wearing and, the correlation between wear and rut depth on the Kouvola rock aggregate test road.

The yearly correlations (1990-91, 91-92, 92-93 and 93-94) between the test results, amount of wear and rut depth results obtained from the Kouvola test road have been parallel over all the years. The clearest deviation is found in the case of the rut depth measured in 1990-91; the correlations between the Nordic ball-mill test and the rut depth (r= 0.26) and between the point-load test and the rut depth (r= 0.12) are very low (Appendices 6 and 7). These results are probably caused mainly by initial compaction and deformation of the asphalt pavement.

Table 20. Correlations between different laboratory test values of Kouvola rock aggregate test road samples. The results of the strength tests and the strength classes are presented in Appendix 3.

	1	2	3	4	5	6	7	8	9
1. Los Angeles value:									
a) All samples	1	0.95***	0.02	0.51	0.69**	0.80***	0.56*	0.14	0.27
b) Rapakivi	1	0.91***	0.69*	0.93***	0.94***	0.90***	0.85**	0.88**	0.74*
c) Non-rapakivi	1	0.93***	0.28	0.26	0.38	0.67	0.34	0.11	0.32
2. Swedish impact value:									
a) All samples		1	0.17	0.34	0.54	0.69**	0.46	0.28	0.07
b) Rapakivi		1	0.53	0.74*	0.83*	0.79*	0.76*	0.70	0.48
c) Non-rapakivi		1	0.02	0.08	0.05	0.44	0.13	0.09	0.03
3. Abrasion value:									
a) All samples			1	0.63*	0.52	0.22	0.64*	0.86***	0.79**
b) Rapakivi			1	0.60	0.73*	0.65	0.40	0.55	0.36
c) Non-rapakivi			1	0.80	0.84*	0.41	0.94*	0.89*	0.93*
4. Nordic ball-mill value:									
a) All samples				1	0.87***	0.77**	0.70**	0.41	0.89***
b) Rapakivi				1	0.90***	0.85**	0.89**	0.88**	0.88**
c) Non-rapakivi				1	0.99***	0.76	0.59	0.46	0.93**
5. Point-load strength index (core Ø 32 mm):									
a) All samples					1	0.82***	0.66*	0.35	0.67**
b) Rapakivi					1	0.94***	0.78*	0.83**	0.68*
c) Non-rapakivi					1	0.80	0.66	0.50	0.95**
6. Point-load strength index (rock aggregate):									
a) All samples						1	0.46	0.08	0.49
b) Rapakivi						1	0.66	0.76*	0.56
c) Non-rapakivi						1	0.24	0.03	0.62
7. Tröger value (rock sample):									
a) All samples							1	0.64*	0.73**
b) Rapakivi							1	0.89**	0.81*
c) Non-rapakivi							1	0.94*	0.76
8. SRK value (rock sample):									
a) All samples								1	0.65*
b) Rapakivi								1	0.81*
c) Non-rapakivi								1	0.69
9. SRK value (pavement core sample):									
a) All samples									1
b) Rapakivi									1
c) Non-rapakivi									1

Table 21. Correlations between different laboratory test values of Kerava rock aggregate test road samples. The results of the strength tests and the strength classes are presented in Appendix 4.

	1	2	3	4	5	6	7	8
1. Los Angeles value	1	0.88***	0.33	0.72*	0.37	0.02	0.16	0.07
2. Swedish impact value		1	0.03	0.04	0.24	0.25	0.28	0.34
3. Abrasion value			1	0.72*	0.65**	0.71**	0.58*	0.75**
4. Nordic ball-mill value				1	0.63*	0.90***	0.73*	0.94***
5. Point-load strength index (core Ø 32 mm)					1	0.51	0.47	0.60*
6. Tröger value (rock sample)						1	0.79***	0.84***
7. SRK value (rock sample)							1	0.79***
8. SRK value (pavement core sample)								1

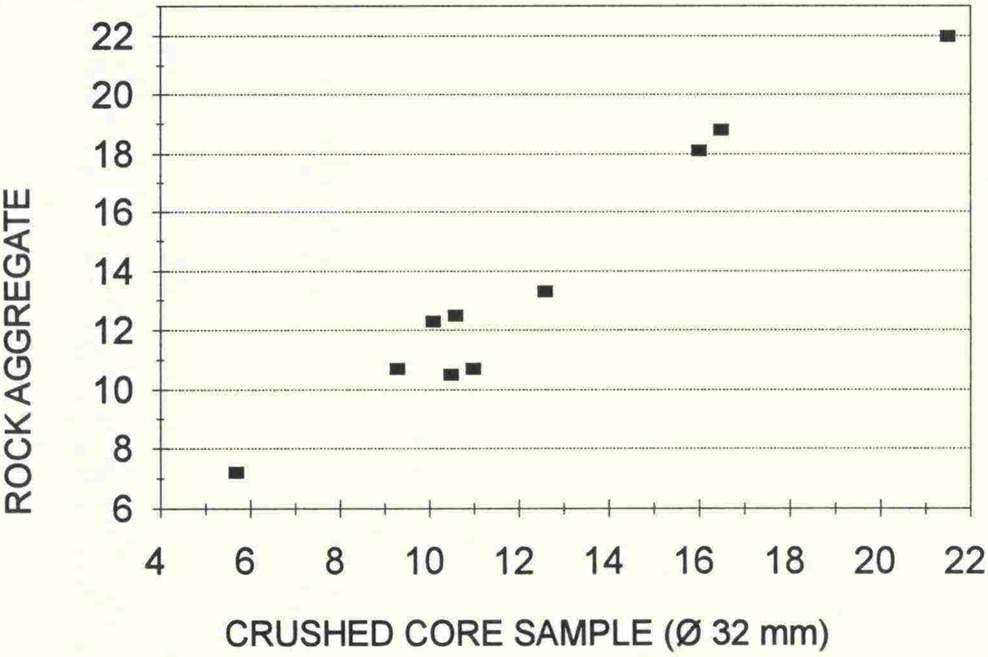
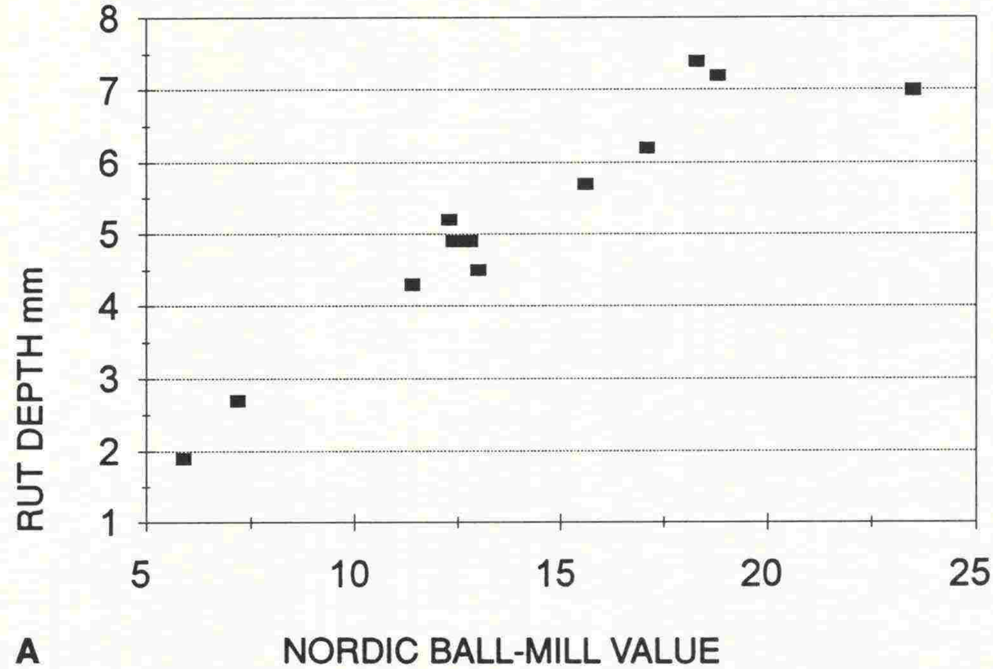


*Fig. 21. Correlation between the rock aggregate and crushed core samples (Ø 32 mm), r = 0.98*** produced with the Nordic ball-mill test performed on the rock samples mentioned in Appendix 2.*



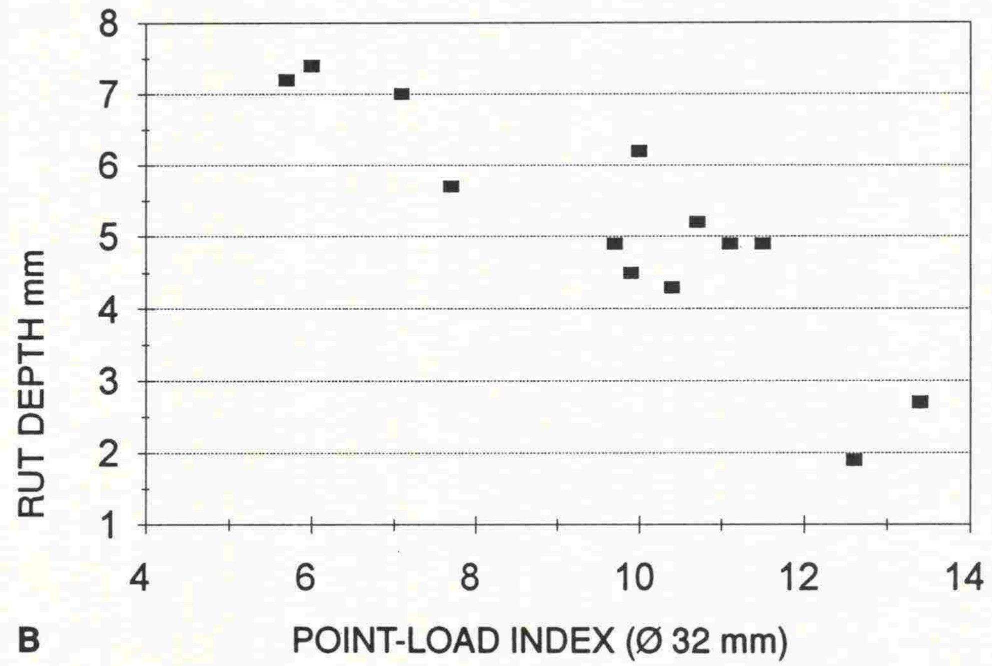
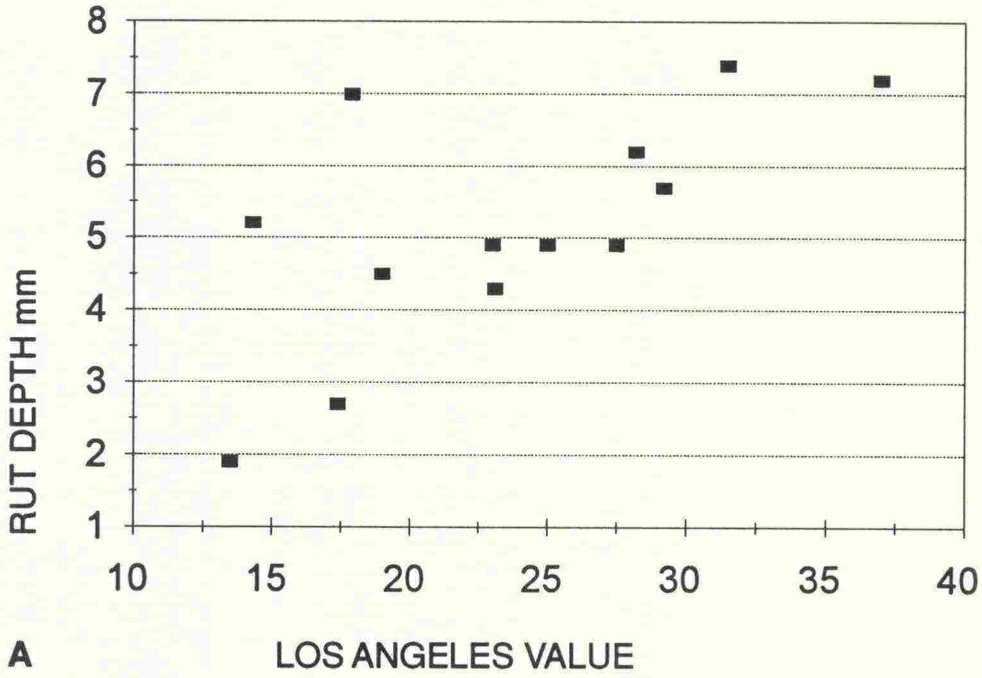


*Fig. 22. Correlations between Nordic ball-mill, r= 0.94*** (A) and point-load, r = 0.89*** (B) tests and rut depths performed on Kouvola rock aggregate test road samples.*



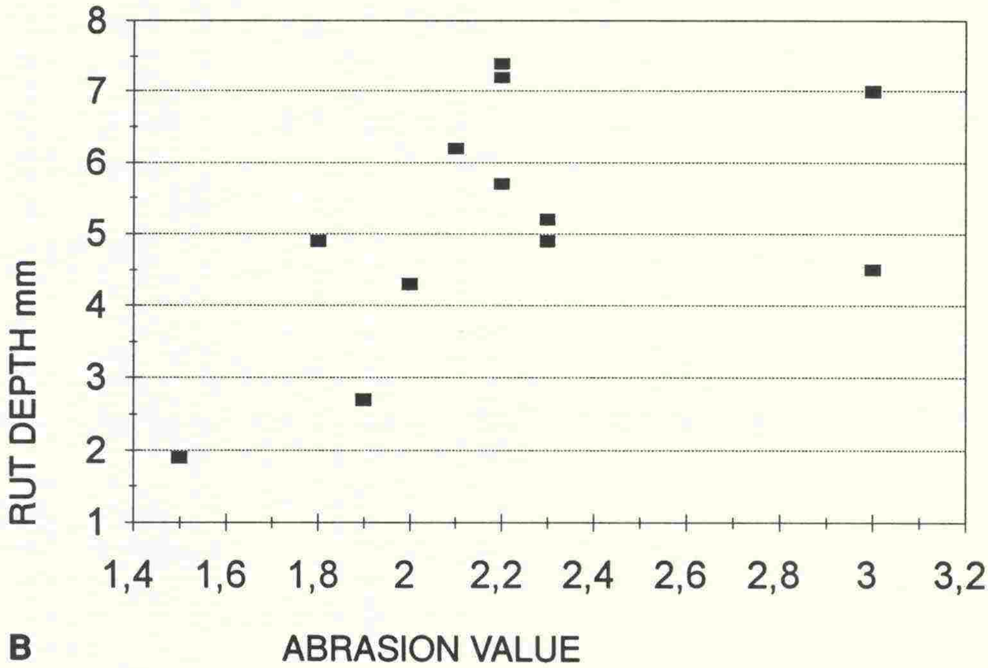


Fig. 23. Correlations between Los Angeles, r = 0.67 (A) and abrasion, r = 0.50 (B) tests and rut depths performed on Kouvola rock aggregate test road samples.*

Table 22. Correlations between different laboratory test values and the amount of wear and rut depth of the Kouvola rock aggregate test road (measured in May 1994). The yearly correlations between the test results, and the amount of wear and rut depth results are presented in Appendices 6 and 7.

	All samples (n=13)		Rapakivi (n=8)		Non-rapakivi (n=5)	
	Wear (cm^2)	Rut depth (mm)	Wear (cm^2)	Rut depth (mm)	Wear (cm^2)	Rut depth (mm)
1. Los Angeles value	0.62*	0.67*	0.91**	0.93***	0.35	0.28
2. Swedish impact value	0.45	0.51	0.77*	0.74*	0.00	0.08
3. Abrasion value	0.57*	0.50	0.54	0.56	0.88*	0.81
4. Nordic ball-mill value	0.90***	0.94***	0.88**	0.99***	0.97**	0.95*
5. Point-load strength index (core Ø 32 mm)	0.92***	0.89***	0.92**	0.92**	0.98**	0.94*
6. Point-load strength index (rock aggregate)	0.80***	0.79**	0.93***	0.86**	0.71	0.68
7. Tröger value (rock sample)	0.70**	0.70**	0.77*	0.86**	0.69	0.57
8. SRK value (rock sample)	0.45	0.32	0.91**	0.85**	0.59	0.51
9. SRK value (pavement core sample)	0.79**	0.84***	0.71*	0.89**	0.99***	0.97**

Table 23. Correlations between different laboratory test values and the amount of wear and rut depth of the Kerava rock aggregate test road (Alkio & Vuorinen 1992a; Kurki et al. 1993). The author has calculated the correlations of the Nordic ball-mill value.

	Wear (cm^2)	Rut depth (mm)
1. Los Angeles value	0.32	0.07
2. Swedish impact value	0.07	0.03
3. Abrasion value	0.80***	0.43
4. Nordic ball-mill value	0.89***	0.62
5. Point-load strength index (core Ø 32 mm)	0.82***	0.57*
6. Tröger value (rock sample)	0.73**	0.29
7. SRK value (rock sample)	0.75**	0.66**
8. SRK value (pavement core sample)	0.85***	0.49

6 CONCLUSIONS

Ranking of rapakivi varieties for the production of asphalt pavements according to alternating norms

In Table 26 is shown the strength quality classes of the rapakivi samples studied according to the FinnRA's work instructions for the years 1987, 1988, 1991, 1993 and 1994. The Table shows that the difference between the quality classes of the same sample dating from different years is mostly only one class (91 %), while not more than 9 % of the samples differ by the margin of 2 classes.

To indicate the consequences of the changes in the quality specification for rock material, a comparison has been made between the quality classifications of rapakivi samples obtained in different years (Table 24). The Table shows that, as regards the rapakivi samples taken as a whole, the work instructions for the year 1987 have been the strictest: only 9 % of the samples were then rated the best, while 28 % fell into the lowest category.

The work instructions for the year 1988 were the least strict. Of the rapakivi samples, 39 % were rated the best and only 4 % as belonging to the lowest category. The reason is that, differing from the instructions for other years, in the work instructions for the year 1988, the defined quality class was not always the lowest strength class (see page 46). The work instructions for the years 1993 and 1994 are almost as strict as those for 1988. Considering the different rapakivi varieties, there are no big differences between the best and the lowest quality class for the same year.

Table 25 shows how different tests affect the quality classification of rapakivi varieties. On the basis of the work instructions for 1987, the quality class was determined to the extent of 61 % by the Swedish impact test alone, of 6 % solely by the Los Angeles test and of 33 % by both tests. Also on the basis of the work instructions for 1988, the main part of the quality classifications was done by the Swedish impact test (58 %).

According to the 1991 work instructions, the quality class of rapakivi samples was determined mainly by the point-load test (74 %), because the porphyritic and the even-grained varieties resist abrasive strain clearly better than point-load strain. However, owing to the good point-load resistance of the dark-coloured varieties, the quality class of the samples was determined by both the abrasion and point-load tests.

In the work instructions for 1993, the limits of the abrasion test were increased and those of the point-load test diminished in comparison with earlier years (Table 5B on page 44). This change can be seen also in the results of present research, namely, in that which test plays the decisive role in classification: the quality class of the samples is not determined by the point-load test (0 %), but by the abrasion test (7 %), and, mainly, by the Nordic ball-mill test (45 %).

In the light of the 1994 work instructions, it is clearer that rapakivi granites are markedly less resistant to strikes (Nordic ball-mill test) than pointed load (point-load test): the quality class was determined in 62 % of the samples solely by the Nordic ball-mill test, in 0 % only by the point-load test and in 38 % of the samples by both tests together.

As regards the reliability of laboratory tests, the development of norms has been positive. The real value of the tests and objectiveness of classification of rock materials remains to be judged after the wearing of different materials used in the paving of roads has been measured and evaluated.

However, on the basis of the quality classification used, the suitability of different rapakivi varieties as asphalt pavement rock materials will be examined next. The quality classification will be the one obtained by tests according to the 1994 work instructions. Quality requirements based on average daily traffic volume have changed in the 1994 FinnRA instructions as compared with the 1992 instructions. In the present study, both quality classes are used.

Wiborgite

Table 26 presents the quality classes of the wiborgite samples studied. Most of the wiborgite samples belong to the IV-V quality classes. This inferior quality class of "typical wiborgite" results from the medium- to coarse-grained groundmass, the euhedral minerals and the clearly observed microjointing. The wiborgitic bedrock of the Wiborg batholith (over 90 %) is mostly in the IV-V quality classes.

The aggregate prepared from this rock is suitable as asphalt paving material on roads where the average traffic volume is less than 1500 (1994) / 1000 (1992) vehicles a day.

With regard to strength, the best wiborgites belong to the III class. Typical of these rocks is their fine- to medium-grained groundmass, abundant fine-grained quartz often occurring in both the groundmass and the ovoids and their only slight microjointing.

The best wiborgitic rock is suitable as asphalt paving material on roads where the average traffic volume is less than 2500 (1994) / 5000 (1992) vehicles a day.

Dark-coloured wiborgite

The dark-coloured wiborgites studied belong to the IV-V quality classes (Table 26). According to the point-load test, the Kuusankoski samples (variety 2A) would fall into the II-III strength classes, but owing to the very weak Nordic ball-mill test values, they must be ranked in the IV-V quality classes. The better properties of the Kuusankoski samples (the smaller grain size of the groundmass and, for example, the clearly slighter microjointing) compared with the samples from the Kaipiainen and Lappeenranta areas (variety 2B) will not greatly affect the quality class.

Thus the dark-coloured wiborgites are suitable at best as asphalt paving material on roads where the average daily traffic volume is less than 1500 (1994) / 1000 (1992) vehicles.

Pyterlite

The five pyterlite samples studied are in the IV-V quality classes (Table 26). The coarse-grained pyterlitic rock with abundant microjointing belongs typically to the V quality class. Hence, according to the 1994 instructions, it is suitable as asphalt paving material on roads where the average daily traffic volume is less than 500 vehicles.

Pyterlite cannot be used as asphalt paving material for main highways.

Table 24. Comparison between the quality classification of rapakivi samples obtained on the basis of the work instructions issued in the years 1987, 1988, 1991, 1993 and 1994. The comparison is made according to the quality classes of Table 26. The rapakivi varieties are explained in Table 15, on page 66.

	BEST QUALITY CLASS / LOWEST QUALITY CLASS				
Rapakivi variety	1987	1988	1991	1993	1994
Porphyritic	13/22 %	43/4 %	20/21 %	12/26 %	12/27 %
Even-grained	4/45 %	33/5 %	27/11 %	18/21 %	18/18 %
Dark-coloured	13/24 %	42/0 %	26/16 %	6/33 %	13/27 %
All varieties:	9/28 %	39/4 %	24/17 %	13/26 %	15/25 %

Table 25. The influence of different tests on the quality classification of rapakivi varieties.
Tests: 1=Los Angeles,
2=Swedish impact,
3=abrasion,
4=point-load,
5=Nordic ball-mill.

Rapakivi variety	WORK INSTRUCTION											
	1987		1988			1991		1993			1994	
	1	2	1	2	3	3	4	3	4	5	4	5
Porphyritic	9 %	57 %	9 %	57 %	0 %	0 %	100 %	0 %	0 %	64 %	0 %	64%
Even-grained	0 %	70 %	0 %	0 %	0 %	8 %	72 %	8 %	0 %	44 %	0 %	56%
Dark-coloured	11 %	56 %	6 %	44 %	6 %	37 %	32 %	16 %	0 %	21 %	0 %	68%
All varieties:	6 %	61 %	5 %	58 %	2 %	12 %	74 %	7 %	0 %	45 %	0 %	62%

Table 26. Quality classes of rapakivi granite samples in 1987, 1988, 1991, 1993 and 1994. The strength classes of the tests are based on FinnRA's directions (Table 5 on page 44). The quality classes of the rock materials have been determined in 1987 by tests 1 and 2; in 1988 by tests 1, 2 and 3a; in 1991 by tests 3a and 4a; in 1993 by tests 3b, 4b and 5a; and in 1994 by tests 4c and 5b. 1= Los Angeles test, 2= Swedish impact test, 3= abrasion test, 4= point-load test, 5= Nordic ball-mill test. The textural features of different rapakivi varieties are explained in Table 4 (page 25) and the observation sites in Fig.1 (page 13).

Rapakivi variety and observation site	Strength classes of the tests									Quality class				
	1	2	3a	3b	4a	4b	4c	5a	5b	1987	1988	1991	1993	1994
1A Wiborgite (1)	III	IV	II	III	-	IV	IV	-	V	IV	III	-	-	V
1A Wiborgite (4)	III	IV	II	II	IV	IV	IV	IV	IV	IV	III	IV	IV	IV
1A Wiborgite (5)	IV	III	II	III	-	IV	IV	-	V	IV	III	-	-	V
1A Wiborgite (6)	IV	-	II	III	-	IV	IV	IV	IV	-	IV	-	IV	IV
1A Wiborgite (7)	IV	IV	III	III	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
1A Wiborgite (10)	IV	IV	II	III	-	IV	IV	IV	IV	IV	IV	-	IV	IV
1A Wiborgite (11)	III	III	II	III	IV	III	III	IV	IV	III	III	IV	IV	IV
1A Wiborgite (12)	III	IV	II	II	III	III	III	IV	IV	IV	III	III	IV	IV
1A Wiborgite (13)	IV	IV	II	III	-	IV	IV	-	V	IV	IV	-	-	V
1B Wiborgite (8)	-	-	II	III	-	-	V	-	V	-	-	-	-	V
1B Wiborgite (9)	-	-	II	III	-	-	V	-	V	-	-	-	-	V
1C Wiborgite (14)	-	-	II	III	-	-	V	-	V	-	-	-	-	V
1C Wiborgite (15)	-	-	II	III	-	-	V	-	V	-	-	-	-	V
1D Wiborgite (2)	III	II	II	II	III	III	III	III	III	III	II	III	III	III
1D Wiborgite (3)	III	IV	II	II	III	III	III	III	III	IV	III	III	III	III
1D Wiborgite (16)	III	IV	II	III	III	III	III	III	III	IV	III	III	III	III
2A Dark-coloured wiborgite (17.1)	III	III	II	II	III	II	II	-	V	III	III	III	-	V
2A Dark-coloured wiborgite (17.2)	IV	IV	III	IV	IV	III	III	-	V	IV	IV	IV	-	V
2A Dark-coloured wiborgite (18.1)	II	III	II	III	III	II	II	IV	IV	III	II	III	IV	IV
2A Dark-coloured wiborgite (18.2)	III	IV	II	III	IV	III	III	IV	IV	IV	III	IV	IV	IV
2B Dark-coloured wiborgite (19)	IV	IV	II	III	-	IV	IV	-	V	IV	IV	-	-	V
2B Dark-coloured wiborgite (20)	-	-	II	III	-	-	V	-	V	-	-	-	-	V
3A Pyterlite (21)	IV	IV	I	II	-	IV	IV	-	V	IV	IV	-	-	V
3A Pyterlite (22)	-	-	II	III	IV	IV	IV	-	V	-	-	IV	-	V
3A Pyterlite (23)	-	-	II	II	IV	IV	IV	-	V	-	-	IV	-	V
3A Pyterlite (24)	-	-	II	II	-	-	V	-	V	-	-	-	-	V
3A Pyterlite (25)	IV	-	II	II	-	IV	IV	IV	IV	-	IV	-	IV	IV
4A Porphyritic rapakivi granite (27)	IV	-	I	II	-	-	V	-	V	-	IV	-	-	V
4A Porphyritic rapakivi granite (28)	-	-	III	III	IV	IV	IV	-	V	-	-	IV	-	V
4B Porphyritic rapakivi granite (26.2)	III	IV	II	III	IV	III	III	IV	IV	IV	III	IV	IV	IV
4B Porphyritic rapakivi granite (29)	IV	-	II	III	IV	III	III	-	V	-	IV	IV	-	V
4C Porphyritic rapakivi granite (26.1)	II	III	II	II	III	II	II	II	II	III	II	III	II	II

Rapakivi variety and observation site	Strength classes of the tests									Quality class				
	1	2	3a	3b	4a	4b	4c	5a	5b	1987	1988	1991	1993	1994
5A Even-grained biotite rapakivi (31.2)	II	III	II	II	III	II	II	III	III	III	II	III	III	III
5A Even-grained biotite rapakivi (38)	III	III	II	II	III	II	II	III	III	III	III	III	III	III
5A Even-grained biotite rapakivi (42)	III	III	II	II	III	II	II	III	III	III	III	III	III	III
5A Even-grained biotite rapakivi (46)	III	IV	II	III	III	III	III	III	III	IV	III	III	III	III
5B Even-grained biotite rapakivi (34.2)	-	-	II	III	-	IV	IV	-	V	-	-	-	-	V
5C Even-grained biotite rapakivi (30)	II	III	II	II	II	II	II	II	II	III	II	II	II	II
5C Even-grained biotite rapakivi (32)	II	II	I	II	I	I	I	II	II	II	II	I	II	II
5C Even-grained biotite rapakivi (33)	I	III	I	II	I	I	I	II	II	III	I	I	II	II
5C Even-grained biotite rapakivi (34.1)	II	III	I	II	II	II	II	II	II	III	II	II	II	II
5C Even-grained biotite rapakivi (40)	II	III	II	II	I	I	I	II	II	III	II	II	II	II
5C Even-grained biotite rapakivi (43)	II	III	II	II	III	II	II	II	II	III	II	III	II	II
5D Even-grained biotite rapakivi (35)	III	IV	II	II	III	II	II	III	III	IV	III	III	III	III
5D Even-grained biotite rapakivi (44)	III	IV	II	II	III	II	II	III	III	IV	III	III	III	III
5D Even-grained biotite rapakivi (45)	III	IV	II	II	III	III	III	III	III	IV	III	III	III	III
5E Even-grained biotite rapakivi (36)	IV	IV	II	II	IV	III	III	IV	IV	IV	IV	IV	IV	IV
5E Even-grained biotite rapakivi (39)	-	-	II	II	IV	IV	IV	IV	IV	-	-	IV	IV	IV
5E Even-grained biotite rapakivi (41)	IV	IV	I	II	IV	IV	IV	-	V	IV	IV	IV	-	V
5F Even-grained biotite rapakivi (31.1)	I	I	I	II	I	I	I	I	I	I	I	I	II	I
5F Even-grained biotite rapakivi (37)	I	II	I	II	II	II	II	II	II	II	I	II	II	II
6A Grey Kymi rapakivi (47)	III	IV	II	III	IV	IV	IV	IV	IV	IV	III	IV	IV	IV
7A Porphyry aplite (64)	II	III	II	II	I	I	I	III	III	III	II	II	III	III
7A Porphyry aplite (65)	III	III	II	II	III	II	II	III	III	III	III	III	III	III
7A Porphyry aplite (67)	II	III	I	II	II	II	II	III	III	III	II	II	III	III
7B Porphyry aplite (66)	I	III	I	II	II	II	II	II	II	III	I	II	II	II
8A Quartz porphyry (68)	I	II	I	I	I	I	I	I	I	II	I	I	I	I
9A Hornblende rapakivi (48)	I	I	II	II	I	I	I	II	II	I	I	II	II	II
9A Hornblende rapakivi (49.1)	I	II	II	II	I	I	I	II	II	II	II	II	II	II
9A Hornblende rapakivi (50.1)	I	II	I	II	I	I	I	I	I	II	I	I	II	I
9A Hornblende rapakivi (50.2)	I	II	I	II	I	I	I	II	II	II	I	I	II	II
9B Hornblende rapakivi (49.2)	III	IV	II	III	IV	III	III	IV	IV	IV	III	IV	IV	IV
9C Hornblende rapakivi (51)	III	IV	II	II	IV	III	III	III	III	IV	III	IV	III	III
9C Hornblende rapakivi (52)	II	III	I	II	II	II	II	III	III	III	II	II	III	III
9D Hornblende rapakivi (53)	III	III	III	III	III	III	III	III	III	III	III	III	III	III
9D Hornblende rapakivi (54)	III	IV	III	IV	III	III	III	III	III	IV	III	III	IV	III
9D Hornblende rapakivi (57)	III	III	III	III	III	III	III	III	III	III	III	III	III	III
9E Hornblende rapakivi (55)	IV	IV	III	IV	III	III	III	-	V	IV	IV	III	-	V
9F Hornblende rapakivi (56)	IV	-	III	III	-	IV	IV	-	V	-	IV	-	-	V
10A Tirilite (58)	II	III	II	III	III	II	II	III	III	III	II	III	III	III
10A Tirilite (59)	III	II	II	III	III	III	III	III	III	III	II	III	III	III
10A Tirilite (63.1)	II	II	II	III	I	I	I	III	III	II	II	II	III	III
10B Tirilite (60)	-	-	-	-	-	-	V	-	V	-	-	-	-	V
10B Tirilite (61.2)	-	-	-	-	III	III	III	-	V	-	-	-	-	V
10C Tirilite (61.1)	III	III	III	IV	II	II	II	IV	IV	III	III	III	IV	IV
10C Tirilite (63.2)	IV	III	IV	IV	III	III	III	IV	IV	IV	IV	IV	IV	IV
10D Tirilite (62)	I	II	II	III	I	I	I	II	II	II	II	II	III	II

Porphyritic rapakivi granite

Porphyritic rapakivi granites usually belong to the V quality class (Table 26). The poor strength resistance is due to the texture (coarse-grained, euhedral minerals) and to the abundant microjointing.

Porphyritic rapakivi granite is not suitable as asphalt paving material on main highways.

In connection with the Jaala-Iitti hornblende rapakivi complex, there occurs a variety differing from the other porphyritic rapakivi granites. Its better strength resistance compared with other samples results from the fine-grained groundmass, the abundance of fine-grained quartz and the lack of microjointing. The quality class of the rock mentioned is II.

This rock is suitable as pavement aggregate on roads where traffic volumes are less than 5000 (1994) / 10 000 (1992) vehicles a day. The occurrence area is, however, so small that its exploitation is not economically justified.

Even-grained biotite rapakivi

The 19 even-grained biotite rapakivi samples studied belong to the I-V quality classes (Table 26). Exploitation of the rock belonging to the I quality class (observation site 31.1) is not warranted because there is not enough of the rock material. So not one of the bedrock areas studied containing biotite rapakivi granites is suitable for exploitation as an asphalt paving material on roads where the daily average traffic volume is over 5000 (1994) / 10 000 (1992) vehicles.

As for asphalt paving material on roads where the required quality class is II, several of the bedrock areas studied (variety 5C) are suitable. Exploitation of bedrock area No. 30 is limited because of its distant location from main highways. The bedrock of observation site 32 should be examined more closely (e.g., diamond core drilling) before possible exploitation.

In the area of observation site No. 34, quarrying had taken place in the early 1960s. Future quarrying will produce II-quality rock aggregate (sample 34.1) as asphalt paving material, while, at the same time, rock aggregate of the V-quality class from the same area (sample No. 34.2) can serve as, e.g., crushed rock for maintenance purposes.

There was also a quarry in the area of observation site No. 43 in the 1960s. Rock material from this area can be used in the near future - as also rock material from observation site 40, which has already been investigated by diamond core drilling.

The even-grained biotite rapakivi granites of the I-II quality classes mentioned are fine- to medium-grained, with a rich occurrence of fine-grained quartz but no microjointing. Biotite rapakivi of the II-quality class occurs in several areas to be exploited.

The best biotite rapakivi can be used for asphalt pavements on roads where the daily average traffic volume is less than 5000 (1994) / 10 000 (1992) vehicles.

The typical medium-grained biotite rapakivi granites belong to the III quality class (variety 5A). These rocks can be used as asphalt paving materials on roads where the average traffic volume is less than 2500 (1994) / 5000 (1992) vehicles a day.

Most of the even-grained biotite rapakivi granites occurring in the Wiborg batholith are coarse-grained (variety 5E). The quality classes of this rock is IV-V, and consequently it cannot be used as asphalt paving material on main highways.

Grey Kymi rapakivi

The medium-grained, even-grained rapakivi studied belongs to the IV-quality class (Table 26). The poor quality of the rock is due mainly to its lack of fine-grained minerals, even grain size and clear microjointing. FinnRA uses this rock as asphalt paving material on highways with little traffic.

Porphyry aplite

The four porphyry aplite samples studied belong to the II-III quality classes (Table 26). The bedrock areas of observation sites 64-66 are too small (under 100 000 tons each) for economically profitable exploitation.

In the area of observation site No. 67, FinnRA quarries rock material of III quality. This rock is also used as asphalt paving material on the No. 7 main highway in the Virojoki area, where the average daily traffic volume is less than 2500 vehicles

Quartz porphyry

The only quartz porphyry sample studied belongs to the I quality class (Table 26). The quartz porphyry dyke, like the others occurring in the Wiborg batholith, is too small (width under 10 m) for quarrying. Consequently, they are not worth exploiting.

Hornblende rapakivi

The quality classes of the hornblende rapakivi granites studied are I-V. The rocks in the Jaala-Iitti complex are typically in the I-II quality classes and in the Lappeenranta area usually in the III quality class (Table 26). Compared with the rocks in the Lappeenranta area, the superior strength qualities of the Jaala-Iitti hornblende rapakivi granites are due to the fine- to medium-grained groundmass and the abundance of hornblende.

In the Jaala-Iitti area, there also occur hornblende rapakivi granites with abundant microjointing (variety 9B), the quality class of which is IV. These rocks are often confined to small areas, and they are not found in the FinnRA quarry areas (variety 9A, observation sites 48 and 50).

In the Lappeenranta area, there also occurs hornblende rapakivi, which, owing to abundant microjointing or the coarse-grained texture, belongs to the V quality class (varieties 9E and 9F). This rock is not suitable as asphalt paving material on main highways.

The hornblende rapakivi of the Lappeenranta area can be used as asphalt paving material on roads where the traffic volume is less than 2500 (1994) / 5000 (1992) vehicles a day.

This is true also of the hornblende rapakivi in the Pyhtää and Hamina areas (variety 9C), the quality class of which is III. FinnRA has quarried rock in the area of observation site No. 52 for, e.g., asphalt paving material on the nearby main highway (traffic volume under 3000 vehicles a day).

The rock of the Jaala-Iitti complex is usable also as asphalt paving material on the most crowded main highways, where the average daily traffic volume is over 5000 (1994) / 10 000 (1992) vehicles. FinnRA has two quarries in the area of this complex.

Dark-coloured, even-grained rapakivi (tirilite)

In the area of this rapakivi variety, the quality of rock and, accordingly, also the classification varies most of all from class II to classless (Table 26).

The rock occurring to the south of Lappeenranta and in the Ylämaa area, where there is abundant microjointing, belongs to the IV-classless categories (varieties 10B and 10C). This rock cannot be used as asphalt paving material on main highways.

The bedrock area studied to the west of Lappeenranta (variety 10A, observation sites 58 and 59) are in the III quality class. The tirilite occurring in the Ylämaa area (observation site No. 63.1), where the microjointing is not abundant, also falls into the III quality class.

These rocks are suitable as asphalt paving materials on roads where the average daily traffic volume is less than 2500 (1994) / 5000 (1992) vehicles.

On the basis of the present study, the best (II quality class) dark-coloured, even-grained rapakivi (variety 10D) is suitable as asphalt paving material on roads where the average traffic volume is less than 5000 (1994) / 10 000 (1992) vehicles a day. Compared with other samples, the minerals of this sample have a smaller grain size, contain abundant fine-grained quartz and show very little microjointing. The exploitation of the bedrock area has been limited because of its distant location from main highways.

Correlations between different tests and the results from test roads

The correlations between different point-load tests are very significant and the standard deviations are small (Tables 15 and 16 on page 66). In the case of rapakivi granites and probably also other granitic rocks, the point-load test can be made with either an Ø 32 mm core sample, an Ø 26 mm minidrill core sample or rock aggregate.

The use of a light, portable minidrill bore facilitates presampling and cuts costs since it eliminates the need to take the blocks to laboratories for boring or to sample diamond core drilling on the sampling site. The minidrill bore will most likely prove useful for sampling non-rapakivi rocks, too, and form a universal tool with the point-load tester in the search and preinventory stages of rock materials.

According to the crushing work instructions issued by FinnRA (Tielaitos 1993b), the point-load test must include "approved pressings" of not less than 16 pcs. On the basis of the results obtained in the present study (minidrill samples of Ø 26 mm), 10 pcs are a sufficient number for reaching a reliable test value.

According to the 1994 FinnRA's crushing work instructions, the strength class of the rock material used for asphalt pavements is determined on the basis of the point-load and Nordic ball-mill tests; and the strength class of the rock material used in the unbound base course of road by the Nordic ball-mill and Los Angeles tests. On the basis of the present rapakivi sampling and the research test results, the correlations between the Nordic ball-mill and point-load tests as well as between these tests and the wear on the test roads are very significant (Tables 19-23). Also the correlation between the rock aggregate and crushed core samples tested by the Nordic ball-mill method is highly significant. Thus the use of the point-load test can be omitted because the Nordic ball-mill test is technically easier to do, is statistically more reliable and is suited to different rock types, also in quality control and guidance during the crushing work and pre-sampling when using core samples or rock aggregate.

On the basis of the rapakivi samples, the correlation between the Nordic ball-mill and the Los Angeles tests is very significant. Thus the quality class of the materials for an unbounded base course obtained from rapakivi granites, and probably also from other granitic rocks, can be determined only by the Nordic ball-mill test. The Nordic ball-mill test alone is probably also suited to testing non-granitic rocks. This question is worth examining by more extensive research.

Finland is trying to have the Nordic ball-mill test approved by the European Union as one of the methods for testing rock materials. If this does not succeed, it would be reasonable to keep the originally American Los Angeles test as one of the testing methods, because it will have the approval of the European Union.

According to FinnRA's target requirements, ruts exceeding 20 mm must not occur in asphalt pavements on main highways. In practice, when the average rut depth is about 15-16 mm, the road will be either milled or coated with a new asphalt pavement.

Table 27 shows the quality classes of the rock materials of the Kouvola rock aggregate test road and also the present amount of wear and the rut depths (measured in May 1994). On the Kouvola test road (main highway No. 6, so-called Pajari straight section), the average daily traffic volume is 4900 vehicles (ADT 1990).

According to the 1994 paving instructions issued by FinnRA (Tielaitos 1994), a road with such a traffic volume requires an asphalt paving rock aggregate of not less than II quality. According to earlier FinnRA's pavement instructions (Tielaitos 1992), an asphalt paving rock aggregate of not less than III quality was proposed (Table 7 on page 45).

Table 27 shows that the quality classes of the rock materials studied vary between classes II and V. Thus, on the basis of FinnRA's 1994 paving instructions, only two rock materials were suitable as asphalt paving material on roads with such a high traffic volume. The average rut depth of the II class rock materials (samples Nos. 7 and 13) is 1.9-2.7 mm and of the III quality rock materials (samples 3, 6, 8, 9, 10 and 12), 4.3-5.2 mm.

The rock material research on the Kouvola rock aggregate test road is not yet completed because, e.g., the rut depths of the III class rock materials are still clearly under the 20-mm limit. As of now, on the basis of the research results obtained, it can be considered probable that the durability of the III class rock material is at least 10 years. Therefore, taking into consideration all the costs, it is probable that on roads with the present average traffic volume, a rock material of III quality can be used. On this basis, FinnRA's 1992 minimum requirements for crushed paving rocks were closer to real conditions than the 1994 instructions.

According to the foregoing experiences, forecasting the durability of roads succeeds very well using the strength classification of paving rock material, as in the present study. It is thus rather easy to calculate the value of rock material for the roads and evaluate how much more it is economical to pay for a good quality rock material.

Table 27. The quality classes of the Kouvola rock aggregate test road samples and also the present amount of wear and rut depths (measured in May 1994). The quality class is determined on the basis of Nordic ball-mill and point-load tests (Appendix 3).

Rock type and place	Quality class	Wear (cm^2)	Rut depth (mm)	Maximum rut depth (mm)
1. Wiborgite Vuorinen	V	177	7.4	8.5
2. Wiborgite Aittovuori	V	189	7.2	9.5
3. Wiborgite Paskomäki	III	124	4.9	8.0
4. Dark-coloured wiborgite Kivistenmäki	V	144	6.2	9.0
5. Grey Kymi rapakivi Kivimäki	IV	155	5.7	8.0
6. Porphyry aplite Paskomäki	III	140	4.9	7.0
7. Hornblende rapakivi Lokonmäki	II	111	2.7	5.0
8. Hornblende rapakivi Huuvakoivunmäki	III	116	4.9	7.0
9. Plagioclase porphyrite Yllikkälä	III	138	5.2	8.5
10. Diabase Lemi	III	142	4.5	8.0
11. Biotite gneiss Telkkälä	V	177	7.0	10.0
12. Granodiorite Teisko	III	131	4.3	6.0
13. Tonalite Koskenkylä	II	93	1.9	3.5

Accessibility of asphalt paving rock materials

Both the bedrock and tested occurrences as well as the public roads with their average daily traffic have been presented in Fig. 1 (page 13). In the Uusimaa Region, in the area of the Wiborg batholith, the total length of the busy main highways Nos. 6 and 7 (ADT over 5000) is 57 km.

The Uusimaa Region has used as asphalt paving rock aggregate for the roads mentioned, as well as other roads in that area, rock from a quarry at Koskenkylä. This tonalite belongs to the I-II quality classes, so it is suited also as asphalt paving material for the busiest main highways (ADT over 10 000).

Rapakivi granite of the I class are found in the Wiborg batholith area only in connection with the Jaala-Iitti hornblende rapakivi complex (FinnRA quarries in the areas of observation sites 48 and 50). The asphalt pavement rock aggregate needs of the Kouvola district roads can be met by that material. However, it has been considered to be too long a way to transport material from the Jaala-Iitti area to the Kotka - Karhula - Hamina areas. And that is why tonalite from Koskenkylä (the neighbouring district) has been used as asphalt pavement rock aggregate for these roads.

In the Lappeenranta area, there occur no I-class rapakivi granites. For the asphalt pavement rock aggregate on the roads in this area, use has been made of plagioclase porphyrite (quality class III) from a quarry belonging to FinnRA in the area around the intersection of the main highways Nos. 6 and 13.

FinnRA roads running nearly 200 km in the Wiborg batholith area have a daily average traffic volume of 5000-10 000 vehicles. These roads are mostly main highways (I class). The highways having such a traffic volume require as the asphalt paving material a rock aggregate in the I (1994) / II (1992) class.

Highway No. 6, between the border of the Uusimaa Region and Kouvola, is problematic because all the bedrock areas with at least II-class rock material are situated relatively far from it. Possible places to obtain asphalt pavement rock aggregate are Koskenkylä, for tonalite, and the Jaala-Iitti area, for hornblende rapakivi (observation sites 48 and 50).

Other areas that lack sufficiently good asphalt paving aggregate are on highway No. 6, between Kouvola - Taavetti and Taavetti - Lappeenranta. For asphalt paving rock aggregate on the road between Taavetti and Lappeenranta, plagioclase porphyrite from the Lappeenranta area has been used. For the road between Kouvola and Taavetti, the asphalt pavement rock aggregate has been transported quite a long distance from the Jaala area.

As for other public roads of the Wiborg batholith, the transport distances of asphalt pavement rock aggregates are relatively short, under 15 km. Besides the public roads maintained by FinnRA, there are in the Wiborg batholith area towns with plenty of busy streets and roads. The general tendency, however, has been for the towns not to pay much attention to the quality of the asphalt pavement rock aggregates used on their roads and streets, very few of them do have laboratories for testing either rock aggregates or real possibilities for choosing among them.

7 SUMMARY

The purpose of the present study is to determine the suitability of the rapakivi granite varieties of the Wiborg batholith for the production of asphalt pavements and to investigate the accessibility of rock materials. In addition, it aims to determine the correlations between various laboratory strength tests done on different rapakivi samples and to compare the findings made on the rock materials used on the Kerava and Kouvola test roads.

The rapakivi granite varieties of the Wiborg batholith are mainly of the porphyritic type (about 90 %), including wiborgite, dark-coloured wiborgite, pyterlite and porphyritic rapakivi granite. In the batholith area, there also occur other varieties, such as even-grained biotite rapakivi, grey Kymi rapakivi, porphyry aplite, quartz porphyry dykes, hornblende rapakivi and dark-coloured, even-grained rapakivi (tirilite).

The rapakivi varieties differ from each other mainly in mineral composition and textural features, and to some extent in regard to the abundance of microjointing and disintegration of the rock. The main minerals of all the rapakivi varieties are potassium feldspar (32-65 %), quartz (21-40 %) and plagioclase (5-28 %). Among mafic minerals, only hornblende (10-15 %) occurs as one of the main mineral constituents of some hornblende rapakivi and dark-coloured, even-grained rapakivi samples .

The strength classes of all the rapakivi samples studied (77 pcs) have been determined by the Los Angeles, Swedish impact, abrasion, Nordic ball-mill and point-load tests. The point-load tests are made on Ø 32-mm core samples (16 pcs parallel samples), on rock aggregates (20 pcs parallel samples) and on Ø 26-mm minidrill core samples (10 pcs parallel samples). The quality classes of the rapakivi samples and, accordingly, their suitability as asphalt pavement rock aggregate is determined on the basis of the work instructions for crushing by FinnRA.

The Pearson correlations between the various strength tests performed on different rapakivi samples and rock materials used on the Kouvola and Kerava rock aggregate test roads have been calculated. Besides, the correlations have been calculated between both the amount of wear and rut depth arrived at in different tests of the rock materials used on the Kouvola and Kerava test roads.

Less than 10 % of the Wiborg batholith bedrock material belongs to the III-quality class or better. The number of bedrock areas of I-II quality that also economically and environmentally are suitable for exploitation is less than 10. A common feature of all the samples studied that belong, according to FinnRA's work instructions for 1994, to the II quality class, is the fine- to medium-grained groundmass, the abundant occurrence of fine-grained quartz and the lack of microjointing. Only one sample from the different porphyritic rapakivi varieties (porphyritic rapakivi granite) belongs to the II class, the others being poorer.

As many as ten of the samples of even-grained rapakivi granites (mainly even-grained biotite rapakivi) studied are at least in the II quality class. Unfortunately, only two of the occurrences warrant exploitation. The exploitation of other areas is limited mainly by the small size of the occurrence (less than 50 000 tons) or by environmental factors.

The quality class of the hornblende rapakivi samples from three observation sites is not below II. All these areas are situated in connection with the Jaala-Iitti hornblende rapakivi granite complex, and in two of these areas FinnRA has a quarry. Also one area of dark-coloured, even-grained rapakivi (in the Ylämaa area) belongs to quality class II. The exploitation of this occurrence is hindered by its unfavourable location with respect to the main roads.

The correlations between different tests done on the rapakivi samples are highly significant. Only the correlation between the abrasion and point-load tests (Ø 26 mm core sample) is significant. The point-load test can be performed using either a core sample or rock aggregate. The use of a light portable minidrill bore facilitates the taking of pre-samples and reduces costs; 10 parallel samples suffice. The tested minidrill bore is probably also serviceable for sampling non-rapakivi granites.

According to the crushing work instructions 1994 (Tielaitos 1993b), the strength class of the bedrock material used for asphalt paving must be determined by the point-load and Nordic ball-mill tests, and the strength class of the rock aggregate for an unbounded base course by the Nordic ball-mill and Los Angeles tests. In the light of present rapakivi research and the investigation of the rock aggregate on the Kouvola and Kerava rock aggregate test roads, there are highly significant correlations between the Nordic ball-mill and point-load tests as well as between these tests and the wear on the test roads. Also the correlation between the parallel rock aggregate and crushed core samples tested by the Nordic ball-mill method is highly significant. Thus the point-load test can be omitted because the Nordic ball-mill test is technically easier to do and, further, suits different rock types, also in quality guidance and control during crushing work and pre-sampling when using core samples or rock aggregate.

On the basis of the rapakivi samples, the correlation between the Nordic ball-mill and Los Angeles tests is very significant. Thus the quality class of rapakivi granites used as rock aggregates in an unbounded base course can be determined by the Nordic ball mill test alone. The Nordic ball-mill test alone is probably also applicable as a method of testing non-rapakivi rock types.

By FinnRA's rules, ruts over 20 mm deep are not allowed in asphalt pavements on main highways. In practice, when the average rut depth in an asphalt pavement is about 15-16 mm, the road will be either milled or coated with a new asphalt pavement. On the Kouvola rock aggregate test road (highway No. 6, so-called Pajari straight section), the average daily traffic volume is 4900 vehicles (ADT 1990). Roads having such a traffic volume require the asphalt paving rock aggregate to be at least of II quality (Tielaitos 1994) / III quality (Tielaitos 1992).

On the basis of FinnRA's 1994 paving instructions, only two rock aggregates were found suitable to serve as paving material on roads with such a heavy traffic volume. The average rut depth of the rock aggregates of II quality (2 test road sections) was 1.9 -2.7 mm, and of III quality (6 test road sections), 4.3-5.2 mm.

The Kouvola test road research on rock aggregates will be continuing for some years because, e.g., the rut depth of the III quality rocks are clearly under the 20-mm limit. In the light of the results obtained so far, it is probable that the durability of III class rocks are not less than 10 years. Thus, taking into consideration all the costs, it is probable that III class rocks can be used for roads with such a traffic volume.

In consequence, the minimum quality requirements in FinnRA's 1992 paving instructions for rock aggregates used as paving material will correspond closer to real conditions than the instructions issued for 1994.

The present study was carried out over a large region of coarse rapakivi granites lacking tough rock aggregate materials. From an area of relatively weak rocks also more durable materials can be found by geological research. The rather uniform (homogeneous) bedrock of the Southeast Finland provided a good possibility for comparing the different strength tests as well as the validity of the quality classification based on them. Specifically valuable from the standpoint of the study have been the results obtained from the test roads built for research purposes using different rock aggregates. They will reveal the weaknesses as well as usefulness of the tests made to evaluate the quality of rock material. The study continues.

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Appendix 1. The types of asphalt pavement mentioned in Table 7 and their suitability for different applications (Tielaitos 1991a; Päällystealan neuvottelukunta (Advisory Committee on Pavements) 1994).

Asphalt concrete (AC), gap-graded asphalt (GAC), stone mastic asphalt (SMA): Six kinds of asphalt concrete are distinguished according to maximum grain size: AC 8, AC 12, AC 16, AC 20, AC 25 and AC 32; similarly, two kinds of gap-graded asphalt: GAC 16 and GAC 20; and four kinds of stone mastic asphalt: SMA 8, SMA 12, SMA 16 and SMA 20.

On highways with heavy traffic (ADT over 5,000 vehicles a day) and main streets, SMA 16-20 or GAC 16-20 is primarily used for the wearing course. On roads where the average volume of traffic daily varies between 1500 and 5,000 vehicles, AC 16-32 is recommended mostly for the wearing course. AC 8-12 and AC 16-20 are suitable for use as a levelling, surfacing and patching mix, as paving for sidewalks and bicycle paths, and as surfacing on special sites (e.g., industrial plants and warehouses).

Guss asphalt (GA): Guss asphalt is used mainly as the wearing course of bridges. The guss asphalt used to surface roadways must always be roughened. Guss asphalt is also used in the maintenance of pavements for patching potholes and tracks.

Base course asphalt concrete (BAC): Three types of asphalt concrete used as base course are distinguished according to maximum grain size: BAC 20, BAC 25 and BAC 32. Base course asphalt concrete is used in the construction of the base course or its upper part. The asphalt mix should be of even granularity. Filler is added as needed and when asphalt base course is used as a temporary wearing course.

Soft asphalt (SA): Three kinds of soft asphalt are distinguished according to maximum grain size: SA 12, SA 16 and SA 20. Soft asphalt is used as the wearing course on routes with pedestrian and bicycle traffic, as separate surfacing of road shoulders, and frequently as pavement on roads with a daily traffic volume of less than 1500 motor vehicles.

Oil gravel (OG): Oil gravel is used as paving on roads with a daily traffic volume of less than 1500 vehicles and as surface treatment and patching material on old oil gravel roads. Crushed gravel containing a small amount of fine aggregate or crushed rock is used as the rock material.

Surface dressing with chippings (SIP): By a surface treatment with chippings is meant a thin layer of crushed aggregate glued with a binder on the wearing course of the pavement. Suitable grain fractions are 6-12 mm and 10-16 mm. The purpose of the surface dressing with chippings is to improve the durability of the pavement, its friction properties and, in the case of light-colored rocks, also its light-reflecting properties. The rock material used as chippings must be clean, even-grained and cubiform. Dirty rock material causes loosening of the aggregates and consequent formation of slippery places.

Surface dressing of a gravel road (SOP): By surface dressing of a gravel road is meant a thin layer of crushed aggregate glued with a binder on the unbound base. Such surface treatment is an alternative method to usual summer maintenance of gravel roads in cases where the volume of traffic does not exceed 500 vehicles per 24 hours. The surface dressing of gravel roads is particularly recommended in case where much dust is raised.

Appendix 2. Parallel results of the Nordic ball-mill test made with rock aggregates and core samples. Rock samples 1-5 are rapakivi granite samples used in this study and samples 1, 3 and 6 are from material used on the Kouvola rock aggregate test road.

Rock type and place	TEST VALUE/STRENGTH CLASS			
	Rock aggregate		Core sample (Ø 32 mm)	
	1	2	1	2
1. Wiborgite (8) Aittovuori	18.8/V	20.7/V	16.5/IV	17.7/V
2. Even-grained biotite rapakivi (34.1) Takamaa	10.7/II	11.2/III	11.0/II	11.1/III
3. Hornblende rapakivi (48) Lokonmäki	7.2/II	7.4/II	5.7/I	5.8/I
4. Dark-coloured even-grained rapakivi (62) Lojomäki	10.5/II	10.9/II	10.5/II	13.2/III
5. Dark-coloured, even-grained rapakivi (63.1) Kivelä	12.5/III	13.0/III	10.6/II	10.7/II
6. Plagioclase porphyrite Yllikkälä	12.3/III	12.4/III	10.1/II	10.3/II
7. Quartzite Palomäki	10.7/II	11.5/III	9.3/II	9.9/II
8. Biotite gneiss Kangasmäki	18.1/V	20.4/V	16.0/IV	17.1/V
9. Pyroxene gneiss Hernemäki	13.3/III	13.7/III	12.6/III	12.9/III
10. Skarn Hernemäki	22.0/V	24.8/V	21.5/V	24.4/V

Appendix 3. The results of the strength tests and the strength classes on the Kouvola rock aggregate test road. Rock samples 1-11 are from the Kymi Region, and from these 1-8 are rapakivi granite samples used in this study. The results of Tröger and SRK tests according to Alkio & Vuorinen 1992a.

Rock type and place	Los Angeles	Swedish impact	Abrasion	Nordic ball-mill	Point-load 1	Point-load 2	Tröger	SRK 1	SRK 2
	TEST VALUE / STRENGTH CLASS								
1. Wiborgite (5) Vuorinen	31.5/IV	25.9/III	2.2/III	18.3/V	6.0/IV	6.4/IV	11.6	9.2	39.8
2. Wiborgite (8) Aittovuori	37.0/-	34.8/-	2.2/III	18.8/V	5.7/V	6.3/IV	16.1	12.5	38.9
3. Wiborgite (16) Paskomäki	27.5/III	26.5/IV	2.3/III	12.8/III	9.7/III	10.1/II	8.1	5.0	31.5
4. Dark-coloured wiborgite (17.1) Kivistenmäki	28.2/III	22.6/III	2.1/II	17.1/V	10.0/II	10.1/II	13.0	9.2	40.1
5. Grey Kymi rapakivi (47) Kivimäki	29.2/III	27.7/IV	2.2/III	15.6/IV	7.7/IV	6.7/IV	11.5	7.4	31.1
6. Porphyry aplite (67) Paskomäki	25.0/II	24.7/III	1.8/II	12.4/III	11.5/II	9.6/III	8.0	5.0	32.1
7. Hornblende rapakivi (48) Lokonmäki	17.4/I	17.1/I	1.9/II	7.2/II	13.4/I	13.3/I	5.6	4.4	27.4
8. Hornblende rapakivi (52) Huuva-koivunmäki	23.0/II	24.2/III	1.8/II	12.5/III	11.1/II	12.2/II	11.2	4.8	33.7
9. Plagioclase porphyrite Yllikkälä	14.3/I	12.3/I	2.3/III	12.3/III	10.7/II	14.9/I	5.8	15.0	37.0
10. Diabase Lemi	19.0/I	16.0/I	3.0/IV	13.0/III	9.9/III	14.1/I	17.4	27.7	39.6
11. Biotite gneiss Telkkälä	17.9/I	13.9/I	3.0/IV	23.5/V	7.1/IV	7.2/IV	12.1	16.5	48.9
12. Granodiorite Teisko	23.1/II	19.2/II	2.0/II	11.4/III	10.4/II	9.1/III	5.1	6.2	32.2
13. Tonalite Koskenkylä	13.5/I	13.5/I	1.5/I	5.9/I	12.6/II	15.7/I	1.2	3.6	18.8

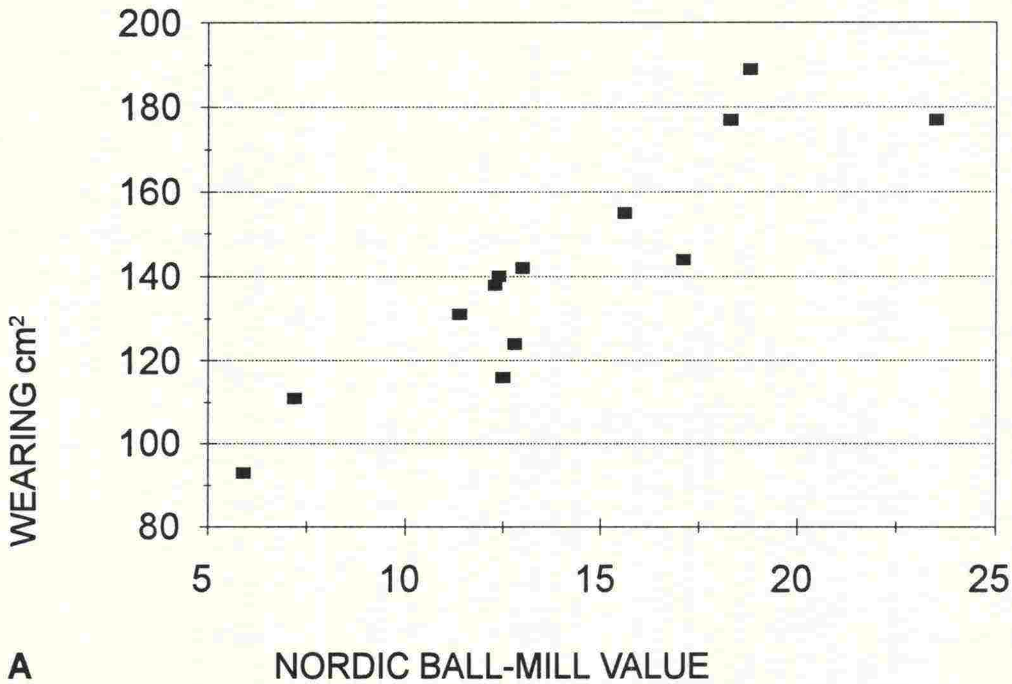
The strength tests are made in following places:
Kymi Region Laboratory of FinnRA: Los Angeles, Nordic ball-mill, point-load (1= Ø 32 mm core, 2= rock aggregate).
Geotechnics Laboratory of FinnRA: Swedish impact, abrasion.
Laboratory of VTT: Tröger (rock sample), SRK (1= rock sample, 2= pavement core sample).

Appendix 4. The results of the strength tests and the strength classes on the Kerava rock aggregate test road (Alkio & Vuorinen 1992a). Nordic ball-mill tests (*) are made in the Kymi Region Laboratory.

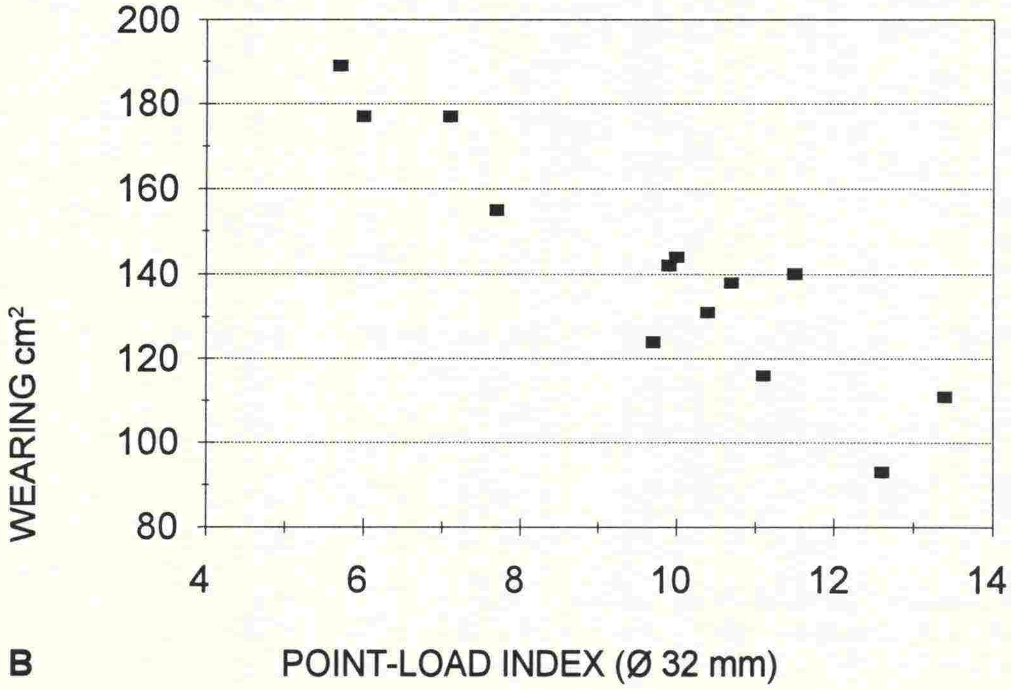
Rock type and place	TEST VALUE / STRENGTH CLASS							
	Los Angeles	Swedish impact	Abrasion	Nordic ball-mill	Point-load	Tröger	SRK 1	SRK 2
1. Intermediate volcanic rock Saarijärvi	12.4/I	8.5/I	1.4/I	5.2/I	13.2/I	9.3	2.6	23.3
2. Tonalite Koskenkylä	11.3/I	8.3/I	1.6/II	5.9/I*	12.6/II	4.4	3.6	26.1
3. Granodiorite Teisko	17.1/I	10.2/I	1.6/II	11.6/III	9.8/III	11.8	6.2	30.7
4. Quartz diorite Kalajoki	12.8/I	8.1/I	2.0/II	-	10.7/II	21.3	22.2	38.2
5. Gabbro Kemiö	14.1/I	8.0/I	2.0/II	13.0/III	9.8/III	16.4	22.2	35.7
6. Gabbro Riihimäki	15.8/I	8.8/I	2.3/III	15.4/IV	11.1/II	18.4	21.8	44.2
7. Diabase Varpaisjärvi	11.9/I	7.3/I	1.3/I	7.6/II	14.9/I	10.1	3.6	29.2
8. Diabase Lemi	16.2/I	10.2/I	2.3/III	13.0/III*	8.0/III	15.1	8.5	38.5
9. Greenstone Tornio	8.2/I	7.1/I	1.2/I	9.8/II	13.1/I	9.2	3.4	28.4
10. Hornblendite Suomusjärvi	9.4/I	6.1/I	1.7/II	14.2/IV	11.9/II	15.4	24.6	38.0
11. Serpentinite Keminmaa	7.5/I	5.6/I	1.6/II	-	9.6/III	13.0	22.6	40.7
12. Amphibolite Kerimäki	12.2/I	7.5/I	2.3/III	-	11.1/II	15.8	23.6	37.2
13. Basic volcanic rock Siilinjärvi	13.9/I	11.4/I	1.6/II	10.3/II	10.9/II	13.6	23.8	31.4
14. Granite Ylivieska	20.1/II	13.7/I	1.6/II	-	10.5/II	8.1	8.4	28.4
15. Intermediate volcanic rock Pyhäjärvi	14.2/I	10.4/I	1.5/I	-	13.2/I	5.7	2.7	26.3

The strength tests are made in the following places:
Geotechnics Laboratory of FinnRA: Los Angeles, Swedish impact, abrasion.
Laboratory of VTT:point-load (Ø 32 mm core), Nordic ball-mill, Tröger (rock sample), SRK (1= rock sample, 2= pavement core sample)
Kymi Region Laboratory of FinnRA: Nordic ball-mill (*)

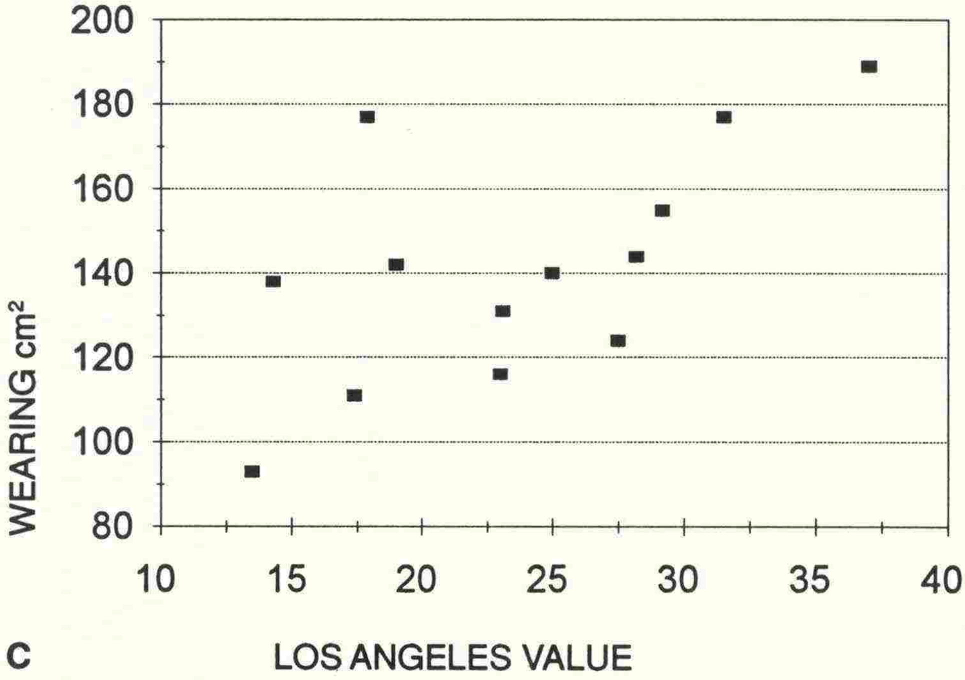
Appendix 5. Correlations between Nordic ball-mill, r = 0.90*** (A), point-load, r = 0.92*** (B), Los Angeles, r = 0.62* (C) tests, rut depth, r = 0.92*** (D) and the amount of wear performed on Kouvola rock aggregate test road samples.



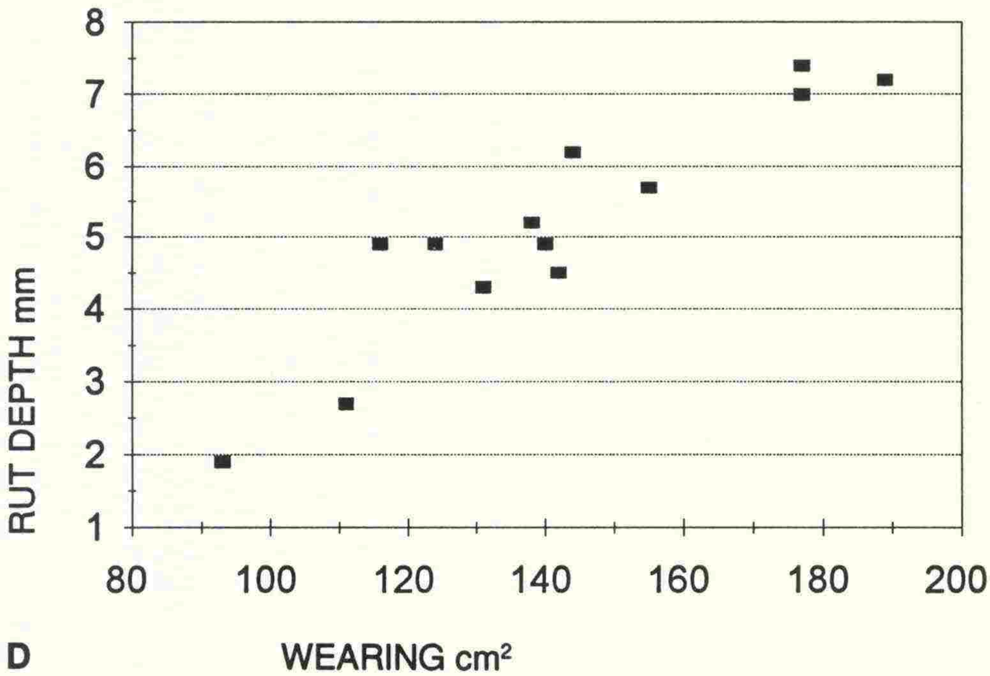
A



B


200
180
160
140
120
100
80
WEARING cm²
10
15
20
25
30
35
40
LOS ANGELES VALUE

C


8
7
6
5
4
3
2
1
RUT DEPTH mm
80
100
120
140
160
180
200
WEARING cm²

D

Appendix 6. Correlations between the amount of wear in different tests on the rock aggregate test road at Kouvola in the years 1990-94, 90-93, 90-92 and 90-91.

WEAR

	All samples (n=13)				Rapakivi (n=8)				Non-rapakivi (n=5)			
	90-94	90-93	90-92	90-91	90-94	90-93	90-92	90-91	90-94	90-93	90-92	90-91
1. Los Angles value	0.62*	0.66*	0.63*	0.53	0.91**	0.95***	0.93***	0.90**	0.35	0.30	0.40	0.36
2. Swedish impact value	0.45	0.50	0.47	0.38	0.77*	0.81*	0.81*	0.79*	0.00	0.06	0.05	0.02
3. Abrasion value	0.57*	0.54	0.58*	0.67*	0.54	0.50	0.44	0.45	0.88*	0.91*	0.93*	0.94*
4. Nordic ball-mill value	0.90***	0.93***	0.92***	0.84***	0.88**	0.94***	0.92**	0.85**	0.97**	0.97**	0.95*	0.84
5. Point-load strength index (core Ø 32 mm)	0.92***	0.92***	0.90***	0.83***	0.92**	0.91**	0.89**	0.87**	0.98**	0.98**	0.97**	0.86
6. Point-load strength index (rock aggregate)	0.80***	0.76**	0.75**	0.67*	0.93***	0.87**	0.86**	0.94***	0.71	0.67	0.68	0.50
7. Tröger value (rock sample)	0.70**	0.76**	0.80**	0.75**	0.77*	0.87**	0.88**	0.70	0.69	0.73	0.77	0.81
8. SRK value (rock sample)	0.45	0.45	0.50	0.59*	0.91**	0.93***	0.93***	0.80*	0.59	0.63	0.67	0.78
9. SRK value (pavement core sample)	0.79**	0.82***	0.84***	0.83***	0.71*	0.84**	0.81*	0.67	0.99**	0.99**	0.99***	0.98**

*** = highly significant correlation (risk level 0.1 %)
** = significant correlation (risk level 1.0 %)
* = almost significant correlation (risk level 5.0 %)

Appendix 7. Correlations between the rut depth found in different tests on the rock aggregate test road at Kouvola in the years 1990-94, 90-93, 90-92 and 90-91.

RUT DEPTH

	All samples (n=13)				Rapakivi (n=8)				Non-rapakivi (n=5)			
	90-94	90-93	90-92	90-91	90-94	90-93	90-92	90-91	90-94	90-93	90-92	90-91
1. Los Angles value	0.67*	0.57*	0.30	0.20	0.93***	0.95***	0.85**	0.01	0.28	0.07	0.01	0.16
2. Swedish impact value	0.51	0.40	0.13	0.24	0.74*	0.75*	0.67	0.20	0.08	0.27	0.36	0.12
3. Abrasion value	0.50	0.50	0.58*	0.43	0.56	0.63	0.51	0.55	0.81	0.69	0.66	0.57
4. Nordic ball mill value	0.94***	0.87***	0.81***	0.26	0.99***	0.98***	0.82*	0.16	0.95*	0.78	0.82	0.54
5. Point-load strength index (core Ø 32 mm)	0.89***	0.86***	0.75**	0.12	0.92**	0.94***	0.87**	0.09	0.94*	0.75	0.77	0.53
6. Point-load strength index (rock aggregate)	0.79**	0.67*	0.55	0.01	0.86**	0.91**	0.87**	0.01	0.68	0.43	0.46	0.26
7. Tröger value (rock sample)	0.70**	0.60*	0.44	0.14	0.86**	0.82*	0.63	0.04	0.57	0.43	0.38	0.36
8. SRK value (rock sample)	0.32	0.38	0.47	0.48	0.85**	0.87**	0.82*	0.00	0.51	0.49	0.42	0.48
9. SRK value (pavement core sample)	0.84***	0.79**	0.80***	0.52	0.89**	0.84**	0.73*	0.10	0.97**	0.87	0.86	0.73

*** = highly significant correlation (risk level 0.1 %)
** = significant correlation (risk level 1.0 %)
* = almost significant correlation (risk level 5.0 %)

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